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NOISE MEASUREMENTS ABOARD SHIP.

BY LIEUTENANT H. A. SIMMS, U. S. NAVY, MEMBER.*

With the increasing interest which engineers are feeling in the matter of noise and its control, accurate comparative and relative measurement of noise has become the real crux of the problem. While the human ear is a marvelous instrument, it differs widely in different people, and even in the same person the two ears will usually vary considerably in sensitivity. To add to this basic difficulty, our brains take a hand and the impulses received are translated with a far from impersonal accuracy, for we often hear what we want or expect to hear in a manner quite discouraging to scientific exactness. The author discusses this problem, the scale of measurement which is slowly being standardized, and the limitations of the present day instruments; and finally undertakes to present a code which can be followed by specialists working in different geographical locations so that the results which they obtain will be as free from instrument error and personal prejudice as is humanly possible.

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Ashore, we live in noisy times. From early morn until late at night our conscious and sub-conscious minds are forced to labor under a handicap of incessant noise which by slow disintegration impairs our nervous systems, reduces our efficiency and eventually leads to a prescribed vacation in a rural district. The rattling, clanking noise of the surface car, the roaring noise of busy street traffic with the intermittent scream of brakes, and all too frequent penetrating blasts of motor driven horns; the distracting clamor of rivet hammers, pneumatic drills and cement mixers incidental to modern methods of building; the Doppler effect of the roaring noise emitted by the speeding subway, all form the existing noise background of life in the cities and densely populated communities. The growing menace of noise has been listed by various authors as the assassin of the nerves, the foe of social welfare, and the greatest menace of the age.

Only a cursory review of developments during the past few decades is needed to indicate that "this plague of noise" is a logical by-product of modern civilization, and that the expression "this is the mechanical age" is synonymous with "this is the age of noise." With ever increasing mechanization in modern life and its resultant ever increasing noise, the future can only be viewed with premonition as a period where noise will vie with disease unless the same mechanical ingenuity which has given life to the mechanical robot of the age shall also be able to give it a soul of quiet.

Public demand has roused systematic effort for the control of noise ashore. A new vocation has therefore developed, that of acoustical engineer, whose special field is the application of noise control measures to machines and buildings to insure freedom from the harmful effects of excessive noise. The terms "quiet" and "efficient" have become practically synonymous as applied to machines, and it is now generally recognized that the conservation of natural resources applies to man power as well as to horsepower, so that today we find a corps of engineers, endowed with the same technical skill which has put efficiency into industry, striving to put quiet into environment.

Afloat, we also live in noisy times. It is common knowledge that ships today are probably the most highly mechanized products conceived and built in this mechanical age. Space and weight limita-

tions and inherent design features all combine to produce ships which generate and amplify noise until the existing noise in certain parts of the ship is well in excess of that encountered ashore. Measurements made on the bridge of a newly commissioned naval vessel have shown a noise level sufficiently high to interfere with oral communications. Unless noise corrective activity accompanies design of higher speed equipment, it is not at all improbable that collisions will occur, caused by the inability of bridge personnel to hear whistle signals over their own ambient level.

Work on the noise problem aboard ship is being energetically pushed by the Bureau of Engineering and the Bureau of Construction and Repair. During the past year, personnel from the Engineering Experiment Station have conducted a series of noise tests on both new ships and ships operating with the Fleet. Although only preliminary test work has been accomplished to date, test results obtained have shown this new test method to be a practicable and valuable inspection test, applicable both to individual machines and ships as a whole.

Noise measurements, to be of the most practicable value, should start in the sub-contractor's plant, should be continued on the assembled unit in the contractor's plant, then on each individual unit after installation in the ship, and finally on the entire ship during the Acceptance Trials. Such a test procedure will necessarily require that noise measurements be made by many engineers in widely separated parts of the country. Test work at the Station during the past year has demonstrated that the proper interpretation and analyses of the results of such noise measurements requires the formulation and adoption of a standard procedure for conducting noise measurements. Such a test code can be followed by all activities conducting these measurements in or for the Navy, to promote mutual understanding.

Toward the formulation of such a test code, the following information on noise and the measurement of noise is presented for consideration. This material has been acquired during the past two years through constant study of text books and technical articles on noise, study of the technique used by commercial acoustical engineers in conducting noise measurements, and experience gained by actually conducting and reporting numerous noise tests both in the laboratory and aboard ship.

Noise is defined as a sound of too short a duration or too complex a structure to be analyzed or understood by the ear. All sounds within the scope of the ear are heard. However, owing to the power of selectivity, not all sounds are definitely impressed on the conscious mind. The sounds forced on the consciousness may be divided into four general classes: preponderant, staccato, mixed, and unusual or warning sounds. Noise may be termed as caused by those sounds which force an unwilling conscious effort in arresting the attention or listening. While continuous noises of the above character may become ordinary and permit attention to be concentrated on other stimuli, there is nevertheless a distinct feeling of relief upon the cessation of even those noises habitually experienced.

Until a few years ago, the human ear had always been relied upon for information as to whether a given noise was objectionable or satisfactory. This method of noise measurement is inherently sound, for even today, with all the knowledge we have of sound and all of the test work accomplished recently, in any problem involving noise measurements the ear is the final judge. But the use of the human ear as a noise measuring instrument is definitely limited by the following inherent weaknesses:

(*a*) No two ears are just alike even when they both belong to the same individual; furthermore, the question arises, whose ears should be used?

(*b*) The sense of hearing, like all the senses, is susceptible to suggestion from within and from without. If we want to hear something and if we believe that we should, it is very likely that we shall.

(*c*) The ear varies from day to day with the general physical condition of the body. Fatigue, sinus trouble, a cold in the head, any one of a number of things may affect the acuity of hearing.

(*d*) The ear is influenced by vibration communicated through the body to the bony structure within the ear.

(*e*) The ear is limited in its ability to differentiate sounds and is not sensitive to small changes in intensity or in frequency.

All of these make the ear unreliable as a precision measuring instrument. In order properly to conduct noise investigations, in-

vestigations which would require comparative noise measurements over a period of time, measurements conducted in different localities under different test conditions, also work on design problems where small improvements are significant as trend indications, it will be apparent that the ear should be supplemented by some form of mechanical measuring instrument. From the above, it will be equally apparent that in the design and use of such equipment, the primary consideration must always be to design and use the instruments so that they will render their judgments in a language which the ear can understand, since, as already stated, in the last analysis we must turn to the ear for a decision.

Sound as related to the ear may be defined subjectively as the sense impression of the organ of hearing and objectively as the vibratory motion which produces the sensation. Connecting the subjective and the objective, there must be some medium of transmission, thus giving three factors for consideration; source, transmission, and reception.

Any elastic body, subjected to changing external forces, will vibrate and set the adjacent medium, in most cases air, into similar oscillation. The sound wave will thus be a series of condensations and rarefactions, periodic with the vibratory stresses. The particles of the medium are placed in motion longitudinally to the source axis, in minute to and fro alternations, impressing their local motion radially to the next outlying boundary particles or layer from the source stress, thus producing spherical zones of alternate motion. The medium as a whole, on cessation of wave motion, is in its initial position. As any vibration is definitely characterized by amplitude, frequency, and amplitude-frequency relation or wave form, sound will be interpreted by these characteristics. For a given frequency, the amplitude determines the loudness, the frequency determines the pitch, and the wave form controls the quality. The simplest form of a vibration is the simple harmonic motion in which the frequency-amplitude relation follows a sine wave; sounds of such characteristics are called pure tones. However, nearly all practical sounds are complex; that is, they consist of a combination of component notes of various frequencies and levels, together with more or less "unpitched sound" which has no particular frequency. In the same way that any

complicated mechanical or electrical vibration can be resolved by means of Fourier's analysis into a simple series of sines, so can any sound be treated as a sum of pure tones.

The exact relation between the physical properties of a sound and its perception include psychological factors which are difficult to measure. This is due to the complexities of the human ear, which is a remarkably rugged, yet sensitive organ. It responds to a frequency range of from 20 to 20,000 cycles per second, in other words, it tunes itself almost instantaneously to wave lengths varying from 56 to 0.056 feet. It responds to air vibration having amplitudes varying in the ratio of 1 to 10^{-12}, or sound intensities ranging from those of hardly more than molecular size (threshold of hearing) to intensities 10 million million times greater without damage. But the ear is not only a hearing organ, it is also a very sensitive pressure gauge. Sounds of very great amplitude will be actually felt by the ears. The greatest sensitivity of the ear lies at or near a frequency of 2000 cycles per second. Cosmic sounds such as the wind in trees, surf on the beach, and the rustle of grass, all approach this frequency, whereas warning sounds lie either below or above.

While measurements in acoustics may be said to date back to Pythagoras, it is only in the last decade that the development of the microphone and the vacuum tube amplifier have furnished a means of translating the extremely small pressures of sound waves into sufficiently large corresponding indications to permit systematic investigation of technical or research problems in acoustics. The fact that standards for noise measurement and acoustical terminology have been adopted as recently as during the past year serves to indicate that progress in what may now be termed this new science of sound has been comparatively slow. An additional reason for late development of mechanical measuring equipment is that sound measurements, to be of any practical importance, must be comparable to measurements made by the ear.

Loudness, as judged by the human ear, is the magnitude of the subjective response to the intensity of sound. Intensity of sound is defined as the sound energy transmitted per unit of time in the specified direction through a unit area normal to this direction, in ergs or watts per square centimeter. The response of the ear, how-

ever, is not proportional to the intensity; it is much more nearly proportional to the logarithm of the intensity. If the intensity of a sound is increased in steps of what seem to be equal increments of loudness, the corresponding intensities form a sequence of the sort 1, 10, 100, 1000 . . . and not of the sort 1, 2, 3, 4 . . . This is due to the fact that the ear obeys the Weber-Fechner law; namely, "The least detectable change in any stimulus is proportional to the intensity of that stimulus." Consequently, a logarithmic scale has been chosen for measurements of loudness. But there is no absolute loudness of a sound; there is only a difference in loudness of two sounds. The loudness of a sound will then be the ratio of the intensity of a given sound to the intensity of a reference sound on a logarithmic scale in units of decibels. The decibel is defined as one-tenth of a bel, and the bel as the fundamental division of a logarithmic scale for expressing the ratio of two amounts of power, the number of bels expressing such a ratio being the logarithm to the base 10 of this ratio. It will be apparent then that the decibel, while being the standard unit for measuring loudness, is nothing more than a ratio, or a percentage and has no absolute value of any kind. For a reference intensity, a sound intensity of 10^{-16} watts per square centimeter has been adopted. This intensity corresponds to the intensity of a reference sound wave having only a single frequency of 1000 cycles per second, generated by a small source, and barely audible to an observer facing the source at a distance of one meter and listening with both ears. The intensity level of a sound is defined as the number of decibels above the reference level.

The measurement of loudness by a determination of the intensity level, as listed above, while complicated enough, is rendered more difficult by the non-linear characteristic of the ear; that is, both the intensity level at the threshold of audibility and at the threshold of feeling are not constant but a function of the frequency. This is shown on Figure 1, a reproduction of the A.S.A. standard equal loudness contours. From these curves, it will be seen that the response of the ear is much different for faint sounds (low levels) than it is for loud sounds (high levels). For example, at a level of 90 decibels, the sensitivity of the ear at 100 and 1000 cycles is the same within a decibel, while at the threshold of

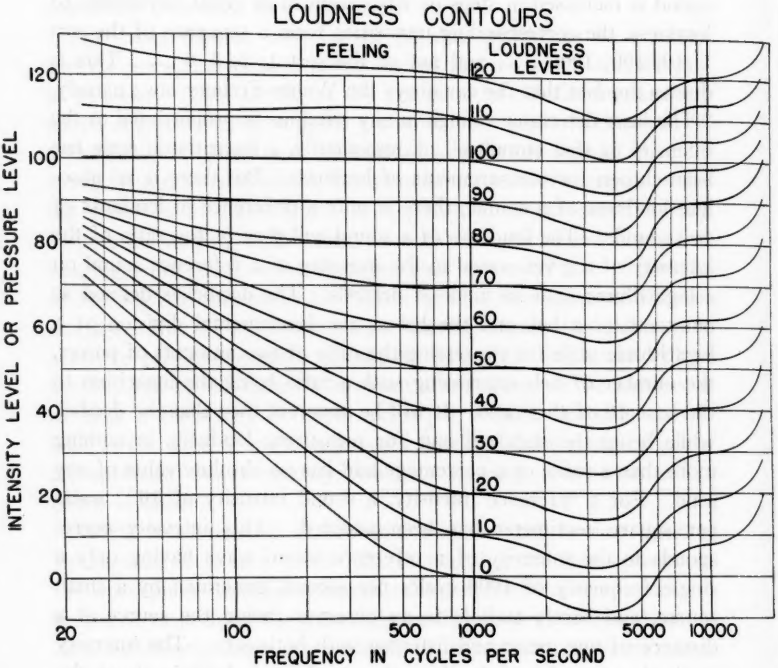


FIGURE 1.

hearing (0 decibels) the difference in sensitivity is nearly 40 decibels, a factor of approximately 100 to 1 in sound intensity. From this it can be seen that measurements of sound intensity and the corresponding loudness sensation will depend upon both the intensity and the frequency and will therefore necessitate special interpretation in many cases. In making sound measurements, this is accomplished by a determination of both the intensity level and the frequency. The intensity level must then be corrected for the measured frequency. For instance, take a sound which has an

intensity level of 50 decibels above a constant physical threshold of 10^{-16} watts per square centimeter. This is a fairly comfortable level, such as a temperature of 70 degrees F. If the frequency is 1000 cycles per second, the sound will be very apparent; but if the frequency is 60 cycles per second, it will be barely audible; and, at 30 cycles per second, it will not be audible at all.

There remains one more necessary conversion before intensity levels in decibels can be presented in units that the ear will recognize as corresponding changes in loudness. The decibel unit furnishes the necessary means for measuring the same kind of changes which the ear recognizes. But the numerical values do not correspond to the sensation. A 100-watt lamp does not look twice as bright as a 50-watt lamp, and a temperature of 100 degrees F. does not feel twice as warm as a temperature of 50 degrees F. Neither is 100 decibels twice as loud as 50 decibels. Formerly, it was contended that the human hearing mechanism possessed no means of judging relative loudness in this fashion, but recent experiments conducted by the Bell Laboratories on the loudness of complex tones have disproved this and furnished the key for this conversion. This relationship between loudness as measured in loudness units and the loudness level measured in decibels is shown on Figure 2, a reproduction of the A.S.A. standard curve, Relation Between Loudness and Loudness Level. It will be seen that, for most of the curve, a reduction in loudness level of 10 decibels corresponds roughly to a reduction of 50 per cent in the apparent loudness, a reduction of 5 decibels corresponds to about 25 per cent reduction in apparent loudness, and so on. This relationship offers a very useful tool, for these percentage changes in loudness represent something which anyone can appreciate; whereas, to most laymen, decibels are still rather confusing. A table showing relations of the various sound units with customary Annapolis noises is included as Figure 3.

The sound measuring instruments used by this Station consist of a sound level meter and sound frequency analyzer manufactured by the Electrical Research Products, Inc., the manufacturing arm of the Bell Laboratories. The purpose of the sound level meter or noise meter is, generally speaking, to measure the intensity or loudness of a sound. The purpose of the sound frequency analyzer is

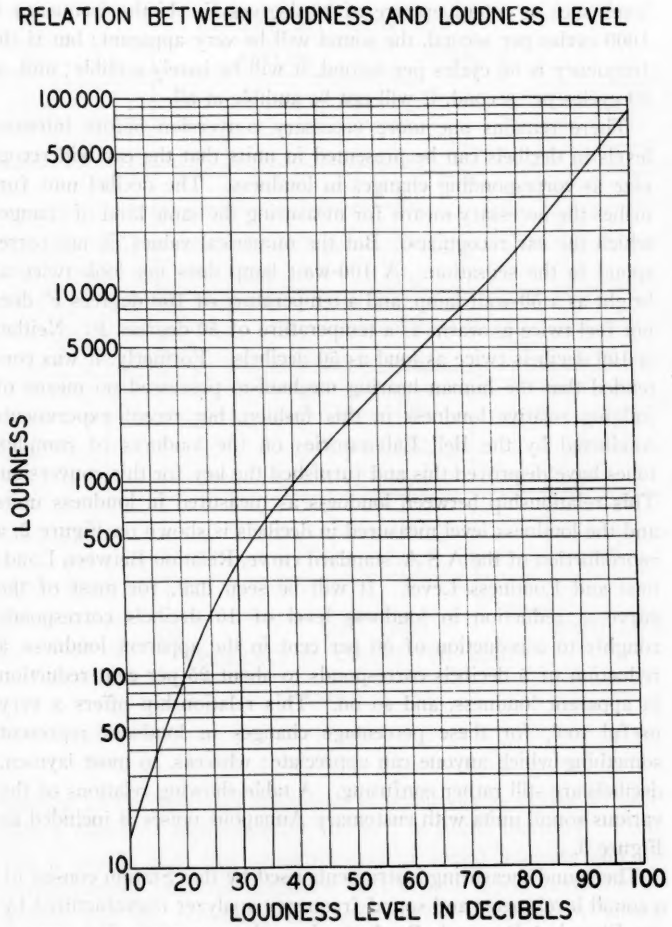

RELATION BETWEEN LOUDNESS AND LOUDNESS LEVEL
LOUDNESS
100 000
50 000
10 000
5000
1000
500
100
50
10
10 20 30 40 50 60 70 80 90 100
LOUDNESS LEVEL IN DECIBELS

FIGURE 2.

COMPARATIVE SOUNDS WITH CORRESPONDING SOUND UNITS

PRESSURE – DYNES PER SQ. CM. OR BARS	INTENSITY – WATTS PER SQ. CM.	RELATIVE ENERGY	LOUDNESS LEVEL IN DECIBELS	AS WE HEAR IT
.000204	1.000×10^{-16}	1	0	THE THRESHOLD OF AUDIBILITY.
.000230	1.259×10^{-16}	1.25	1	
.000256	1.585×10^{-16}	1.6	2	
.000289	2.000×10^{-16}	2.0	3	
.000325	2.520×10^{-16}	2.5	4	
.000410	4.000×10^{-16}	4.0	6	
.000516	6.310×10^{-16}	6.2	8	
.000647	1.000×10^{-15}	10	10	
.00205	1.000×10^{-14}	10^2	20	
.00647	1.000×10^{-13}	10^3	30	HOME IN SUBURBS AT MIDNIGHT. WINDOWS CLOSED COSMIC NOISE IN RURAL DISTRICT. COLD STILL NIGHT.
.0205	1.000×10^{-12}	10^4	40	NAVAL ACADEMY LIBRARY AT NOON.
0647	1.000×10^{-11}	10^5	50	
.205	1.000×10^{-10}	10^6	60	QUIET OFFICE, DIRECTORS OFFICE – E.E.S. – AT 12:30 P.M.
647	1.000×10^{-9}	10^7	70	MESS HALL – BANCROFT HALL – JUST BEFORE COMMAND "SEATS."
2.05	1.000×10^{-8}	10^8	80	
6.47	1.000×10^{-7}	10^9	90	MESS HALL – BANCROFT HALL – DURING NOON MEAL – 2200 MIDSHIPMEN PRESENT. TAKEN IN CENTER OF MESS HALL. SURFACE STREET CAR CROSSING TRACK INTERSECTION.
20.5	1.000×10^{-6}	10^{10}	100	AUTOMOBILE HORN AT 20'. AVERAGE OF 13 AUTOMOBILES
64.7	1.000×10^{-5}	10^{11}	110	30' MOTOR LAUNCH – 5' FORWARD OF BUDA DMR8 – 17 100 HP. ENG. AT 1000 R.P.M. TAKE-OFF OF AN EASTERN AIRWAYS TRANSPORT PLANE AT 100 FEET. BROWNING GROUND TYPE – MODEL 1917 – 30 CAL. MACHINE GUN AT 10 FEET.
205.0	1.000×10^{-4}	10^{12}	120	THE THRESHOLD OF PAINFUL FEELING. DESTROYER BELL TYPE WHISTLE AS HEARD ON THE BRIDGE.
647.0	1.000×10^{-3}	10^{13}	130	10.3U3 SEAPLANE – FULL THROTTLE – WASP R1340-12 ENGINE AT 1750 R.P.M. MICROPHONE 8 FEET FROM WING TIP.

FIGURE 3.

to segregate for measurement or study the sound level at a certain frequency or band of frequencies and suppress or eliminate all others.

The sound level meter consists essentially of a non-directional dynamic microphone, an amplifier, and a means, such as a rectifier and indicating meter, for measuring the output voltage of the amplifier. This instrument is manufactured in accordance with the A.S.A. Standards for Sound Level Meters and is provided with a range from 25 to 125 decibels above a reference sound level of 10^{-16} watts per square centimeter (0.000204 dynes per square centimeter or 0.204 millibars) at 1000 cycles per second. As previously stated and shown on Figure 1, the ear does not evaluate loudness by sound intensity and frequency. To compensate for this scalar inconsistency of the ear, the meter is designed for alternative flat frequency response, or response simulating the frequency response of the ear for noise levels of 70 to 40 decibels above the reference level. The flat frequency response is for use in connection with the frequency analyzer, or alone for measurements at high noise levels. The 70 or 40 decibel responses can be chosen for use and introduced by switching in the proper filter networks. Figure 4 shows curves of the overall free field frequency response of the various weighting networks built into this meter.

The analyzer operates as an attachment to the sound level meter, to which it is connected when required by a suitable cord and plug. The sound energy picked up by the microphone is passed through part of the noise meter amplifier and then to the analyzer. The latter passes only those frequencies in the band to which it is tuned and stops all others. Those passed are transmitted back to the sound level meter, further amplified and measured on the regular indicating meter of the sound level meter. Either sharp or broad tuning can be used, that is, measurement of the sound level in band widths of either 20 cycles or 200 cycles is provided for by a suitable switch on the analyzer. Means are provided for quickly and accurately calibrating both instruments in the field. Both instruments are battery operated and portable.

When the object of the test is the making of overall noise measurements (summation of the noise components at all frequencies), the results desired must always be borne in mind, and the test

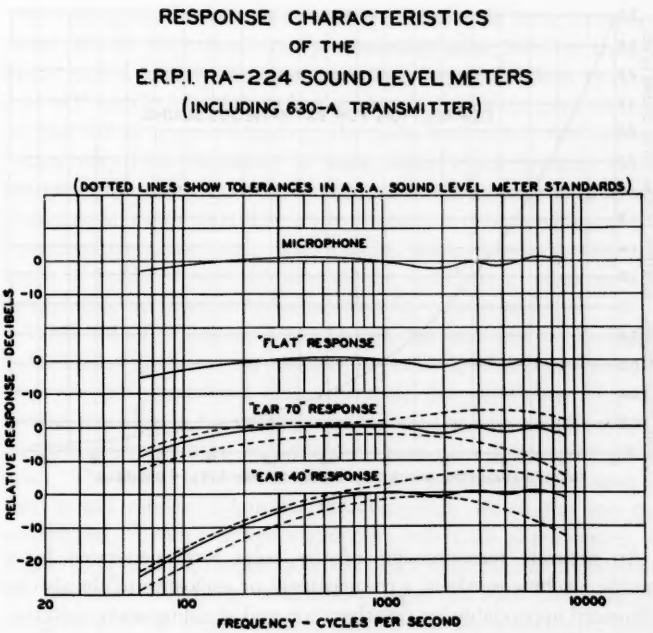


FIGURE 4.

planned and conducted to obtain these results and to eliminate extraneous sources of noise. This is due to the fact that there are certain limitations to the microphone as an electrical "pick up" for the sound level meter; i.e., the microphone and the sound level meter cannot discriminate between the noise from a combination of noises unless this noise differs radically from the others.

In making a noise measurement of a specific machine or noise source, it is necessary to determine the part of the total noise that is generated by other noise sources in the vicinity. If the noise level generated by these extraneous sources is within 10 decibels of the noise generated by the source being measured, it is desirable to eliminate the extraneous components by stopping the machinery responsible for them. If this cannot be done, the theoretical corrections can be made to the total noise measured by use of the curve shown as Figure 5.

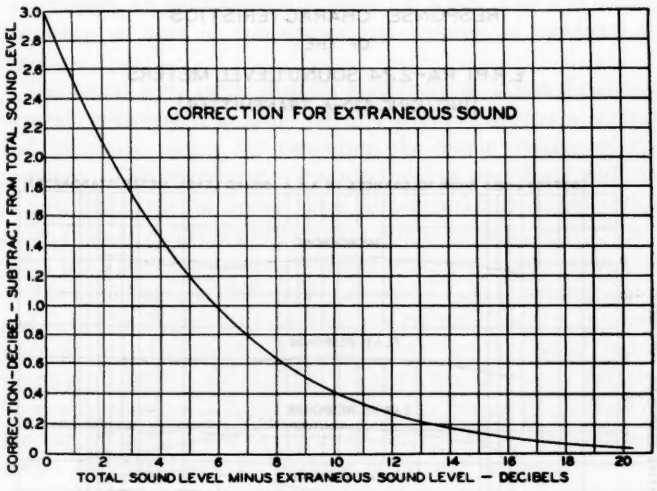


FIGURE 5.

An accurate measurement of the noise level generated by a specific machine inside of a compartment or enclosure might also be influenced appreciably by reverberation and standing wave patterns. Consideration of the effects resulting when noise generators are installed within a compartment shows that the noise will usually be reflected back and forth many times from the reflecting surfaces, and so give rise to complicated distribution of intensity within the compartment. At any point within the space, the total noise level is the result of two effects; namely, the direct noise which reaches the point without first being reflected, and the indirect noise which arrives after suffering one or more reflections from the surrounding surfaces. In general, there will be little correlation between intensity and distance to the source. The intensity may or may not decrease inversely as the square of the distance. It may even be found that at certain points remote from the source the sound is more intense than at positions much closer. The effect of compartment reflections upon noise measurements can usually be made small by placing the microphone close to the source, and by taking a number of measurements about the source.

In making noise measurements in spaces such as living compartments aboard ship where the predominant noise level is from a single source, usually the ventilating fan, large variations in noise level will usually exist from place to place. A measurement close to the fan will be quite misleading; the noise level a few feet further distant may have decreased to some value which remains fairly constant throughout the rest of the space. In making such measurements, an effort should be made to obtain a determination of the representative noise level. This can be obtained only by taking a series of readings with the microphone in different locations, and then picking the representative location for measurement.

While all of the above listed factors can and will cause appreciable errors in the results obtained on noise level measurements if they are not considered and corrected, the possibility of most serious error lies in the improper selection of the frequency weighting network to be used with the particular noise level being measured. The sound level meter must always be designed and used so that it will render judgments in a language which the ear can understand. From a design standpoint, reference to the curves on Figure 1 shows that theoretically for exact loudness determinations, the frequency weighting should be changed for each measurement to agree with the equal loudness contours of the sound level being measured. For practical purposes, however, this has been found to be an unnecessary refinement. A frequency weighting response for a sound level of 40 decibels can be used for the measurement of low sound levels, a frequency weighting response for a sound level of 70 decibels can be used for the measurement of intermediate sound levels, and the flat response or no weighting can be used for the measurement of high sound levels. In other words, a sound level meter equipped with these three frequency response characteristics, if used properly, will give comparative measurements of noise which will agree very closely with comparative measurements of noise as made by the human ear. Electrical filter networks, operated by a selector switch, are installed in most sound level meters, providing for noise measurements on either of these three frequency responses. The networks are designed in accordance with the curves shown on Figure 4.

Consideration of discrepancies possible in noise measurements made aboard ship, if cognizance is not taken of the above listed variables and inconsistencies inherent in such test work, has led to the adoption by the Station of the following procedure for making and reporting such measurements:

(*a*) Calibrate and adjust instruments before tests and as often as necessary during test to insure proper circuit voltages and accurate readings.

(*b*) Take sufficient determinations with microphone in different locations to eliminate as much as possible the "standing wave effect," and insure measurement of a representative noise level from apparatus or in compartment being measured.

(*c*) Select and use frequency weighting networks for overall noise levels in accordance with the following:

40 decibels ear response for noise levels below 60 decibels.

70 decibels ear response for noise levels ranging from 60 to 80 decibels.

Flat response for noise levels above 80 decibels, and with sound frequency analyzer.

(*d*) Report overall noise level in decibels, zero reference level, and frequency weighting network used.

(*e*) Report ambient noise level.

(*f*) Report location of microphone such as distance and direction of microphone from source of noise, or, if measurement is being made in a living compartment or similar location, give relative location and height of microphone.

(*g*) Report all test conditions affecting the accuracy of each determination such as, speed changes, other machinery in operation, etc.

It is considered that adoption of the above procedure as a tentative Code for Noise Measurement would assure comparative results by different observers in different locations. Intent, of course, is that the above would be a general guide, subject to changes resulting from further experience. Blind adherence will not assure success. Comprehension of demands of the individual situation, and exercise of initiative and ingenuity to achieve desired results will be necessary.

THE STOPPING OF SHIPS.

By Rear Admiral S. M. Robinson, U. S. Navy, Member.*

This article is of particular interest to the ship, engine, and propeller designer. In it, Admiral Robinson has restated, and simplified equations covering ship movement in the transient period of starting, stopping, and backing, which he developed and published in the Journal *twenty-two years ago. Through the years additional data has become available to check or modify the constants originally derived, and this has been used in recasting the old equations. The discussion is timely because of Mr. W. E. Thau's recent article on the same subject published in the Transactions of the American Society of Naval Architects and Marine Engineers, Volume 45, 1937.*

In 1916, the author published, in this Journal, a paper dealing with all phases of ship motion—ahead motion, astern motion, and turning, all of these, both with propellers rotating and with them stopped. The data given therein have stood the test of time but the equations used were rather clumsy and it is proposed here to develop new equations from the data given, using integral calculus to derive more simple equations. The data given in the paper of the 1916 Journal have been rather widely discussed both here and abroad and the one point of criticism noted is that no account was taken of the entrained water in calculating the mass to be stopped. Experience has shown that this criticism was not justified and the displacement of the ship will be used, as before, to obtain the mass.

Before proceeding to develop the equations for stopping, it is believed to be worth while to give a brief description of the action

* Compensation Board, Navy Department, Washington, D. C.

of a screw propeller under various conditions of operation in order to clear up certain superstitions and misunderstandings that still exist in regard to the reversal of propellers. At the Fall meeting of the Naval Architects and Marine Engineers in 1937, Mr. R. H. Tingey, of the Fore River Shipbuilding Company, gave a very complete explanation of the action of a propeller under all conditions of service; this explanation is so simple and concise that a resumé of it will be given here.

Figures 1 to 5, inclusive, give a graphic representation of the forces acting on a propeller blade under various conditions. Figure 1 represents the blade of a propeller when it is driving a ship ahead under normal conditions. Figure 2 represents the condition of a propeller revolving freely, due to the motion of the ship. Figure 3 represents a propeller held stationary, while the ship is going ahead. Figure 4 represents a propeller revolving astern while the ship is going ahead. Figure 5 is a velocity diagram of ship and propeller with reference to the water.

In Figure 5, *a* denotes rotational velocity of the propeller in the ahead direction; *b* denotes the ahead velocity of the ship; *c* is the resultant velocity of the propeller through the water. The velocity represented by the vector *d*, shown in Figure 1, is the velocity of the water, relative to the blade, and is equal to and opposite in direction to *c*, in Figure 5. Referring to Figure 1, the force due to the action of the water, flowing with velocity *d*, against the blade, can be represented by two forces, the torque Q, which resists rotation, and the thrust T, which propels the ship forward.

Referring again to Figure 5, if we remove all driving torque from the propeller, its speed will drop to about two-thirds normal value and this will be represented by *f* in the velocity diagram; the resultant velocity will now be represented by *g* and the relative velocity of the water will be *h*, as shown in Figure 2 (equal to and opposite in direction to *g*). The water flowing against the blade with velocity *h*, can still be represented by the two forces Q and T, but they are now opposite in direction to those shown in Figure 1 because the water is striking the other face of the blade. It will be noted that the torque now causes rotation of the propeller in the

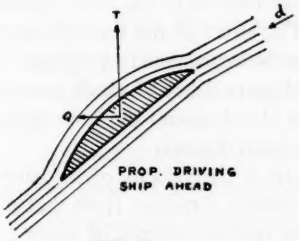


FIG. 1

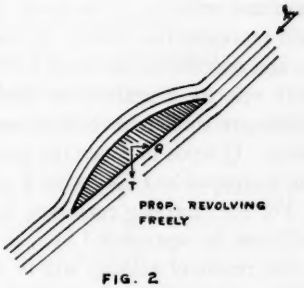


FIG. 2

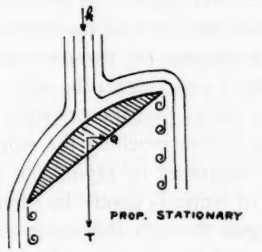


FIG. 3

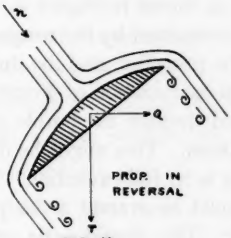


FIG. 4

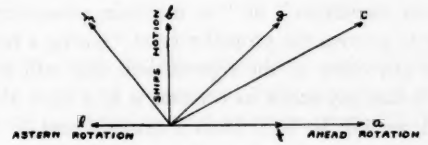


FIG. 5

ahead direction (instead of resisting it as in Figure 1) and the thrust T tends to stop the ship (also the reverse of Figure 1).

Again referring to Figure 5, if we bring the propeller to rest, its velocity will be zero and *b* will represent both ship's velocity and resultant velocity of the blade through the water. In Figure 3, *k* will represent the velocity of the water relative to the blade (equal to and opposite in direction to *b*). The effect of the water flowing with velocity *k* against the blade can be represented by Q and T which are similar to those shown in Figure 2 but of much greater value. Q tends to rotate the propeller ahead against the force holding it stopped and the thrust T slows down the ship.

For the reversing condition, in Figure 5, the velocity of the blade will now be represented by *l*, in the reverse direction from that of *a*; the resultant velocity will be *m*; the relative velocity of water to blade will be represented by *n* (equal to and opposite in direction to *m*), as shown in Figure 4. Here again the force of the water can be represented by the torque Q, which opposes the reverse rotation of the propeller, and the thrust T, which slows down the ship.

An examination of Figures 3 and 4 shows that the propeller has passed through the burble point, even before reaching the stopped condition. This might be differently expressed by saying the propeller is in full cavitation. The flow of water is about the same as it would be around a flat plate dragged through the water at an angle. This should settle, once and for all, the question of whether a ship can be stopped more quickly by operating at reduced torque "to prevent cavitation" or "to maintain possession of the propeller" or to prevent the propeller from "boring a hole through the water" or any other of the superstitions that still seem to persist. The fact is that any screw in reversal is in a state of extreme cavitation and, as will be seen from Figures 4 and 5, the thrust for stopping the ship is a function of the torque (or revolutions) used in reversal—the greater the torque, the faster the stopping. The above theory has been confirmed by model tank tests and by numerous reversal tests.

We shall now proceed to develop equations for all conditions of stopping ships. The following symbols will be used—

H = head-reach of the ship (in feet), in passing from speed v_1 to speed v.

t = time (in seconds) required for a ship to pass from speed v_1 to speed v.

D = displacement of the ship (in tons).

W = weight of the ship (in pounds).

C = the fraction of full load torque used in reversal.

v = speed of the ship at any moment (in feet per second).

V = speed of the ship at any moment (in knots).

v_1 = speed of the ship at beginning of deceleration (in feet per second).

V_1 = speed of the ship at beginning of deceleration (in knots).

v_{FP} = speed of the ship at full power (in feet per second).

V_{FP} = speed of the ship at full power (in knots).

R = resistance of the ship at any moment (in pounds).

R_{FP} = resistance of the ship at speed v_{FP} (in pounds).

T = thrust of the propellers at any moment (in pounds).

T_{FP} = thrust of the propellers at speed v_{FP} (in pounds).

Q = torque of the propellers at any moment (in pounds-feet).

Q_{FP} = torque of the propellers at speed v_{FP} (in pounds-feet).

S.H.P. = shaft horsepower of the ship at speed v_{FP}.

E.H.P. = effective horsepower of the ship at speed v_{FP}.

R.P.M. = revolutions per minute of the propellers at speed v_{FP}.

1 Knot = 6080 feet.

g = 32.16.

For the sake of simplicity, the values of T and Q will be treated as if the entire power of the engines were developed on one propeller. This will not make any difference in the result obtained but will save some arithmetic.

We obtain the full power torque from the equation—

$$Q_{FP} = \frac{\text{S.H.P.} \times 33000}{2\pi \times \text{R.P.M.}} = \frac{5250\ \text{S.H.P.}}{\text{R.P.M.}}$$

To obtain the value of Q, which is to be used in the equation for finding T, we have—

$$Q = CQ_{FP}$$

The value of C will be determined by the individual design of propelling engine. For example, it will probably have a maximum value of about 1.2 for naval reciprocating engines; Diesel engine ships will vary from about .8 to 1.0. For turbines and electric drive ships, it will have to be obtained from each design; ordinarily geared reversing turbines will furnish about 50 per cent of the ahead torque after the propellers are reversed.

The resistance of the ship can be obtained from the effective horsepower. We have—

$$R_{FP} = \frac{E.H.P. \times 33000 \times 60}{V_{FP} \times 6080} = \frac{326\ E.H.P.}{V_{FP}}$$

The resistance will vary as the square of the speed of the ship; therefore—

$$R = R_{FP} \times \left(\frac{V}{V_{FP}}\right)^2$$

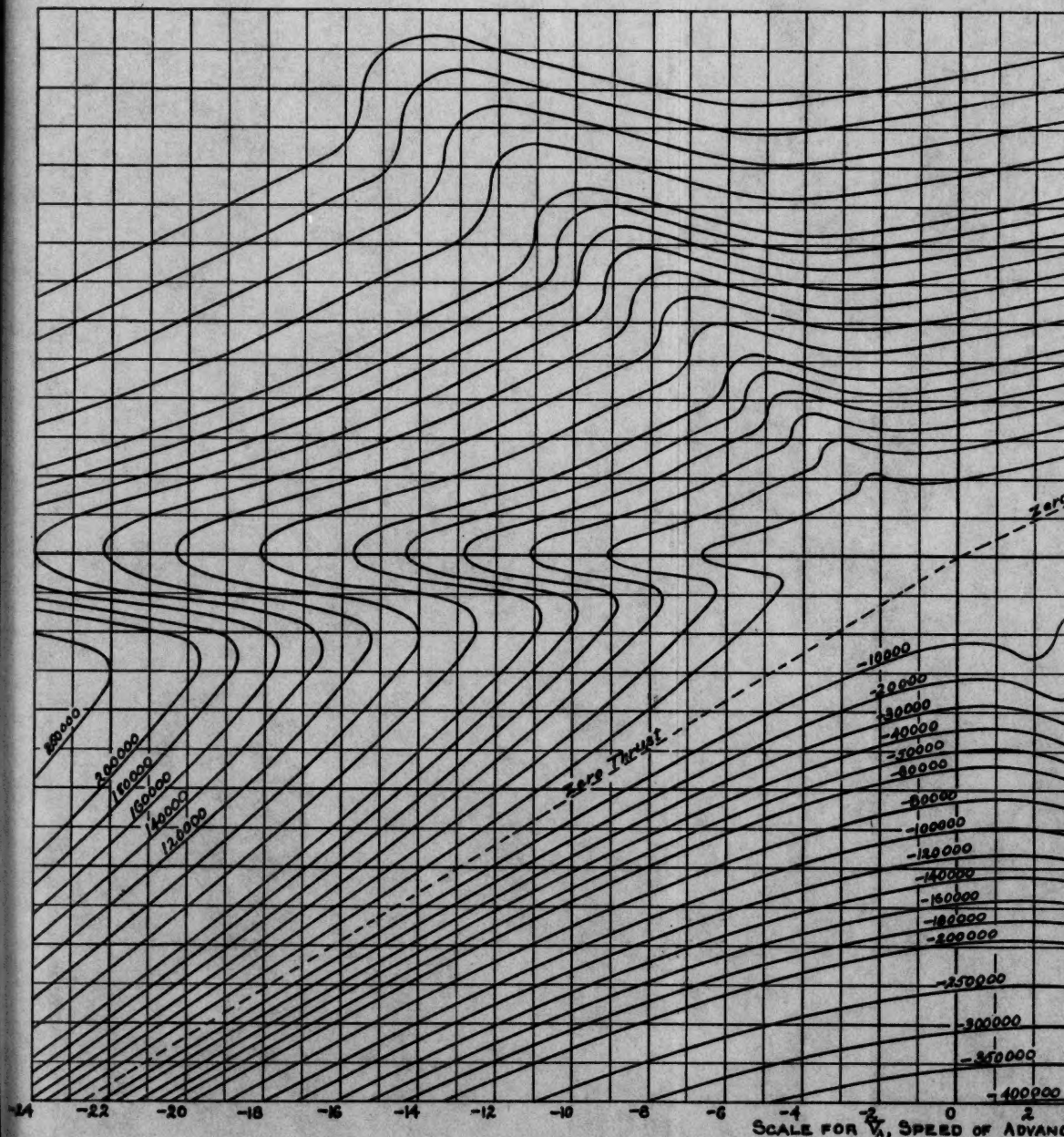
In the paper published by the author in the 1916 JOURNAL, there was given a chart of torque curves of the *Delaware*. A chart of thrust curves was also prepared at the same time but not published at that time; these charts are both given in this paper. From these charts we can obtain the thrust at any speed of the ship and for any value of the propeller torque. The total force stopping the ship is the sum of the resistance R and the thrust T; it will be necessary to have both of these forces in terms of the same base value if we are to use them in an equation. We have already deduced the value of R in terms of R_{FP}; therefore we must also obtain T in terms of R_{FP}. Using the thrust and torque charts we can plot curves of speed against T, expressing the latter as a fraction of R_{FP}; we shall find that we have a set of highly complicated curves (a set for each value of Q) for which no simple equation can be derived. However, for our purposes, the curves can be represented accurately enough by a simple equation, which is—

$$T = R_{FP}\left[\ 1.1C + \left(\frac{V}{V_{FP}}\right)^2\ \right]$$

CONTOUR CURVES OF THRUST OF THE U.S

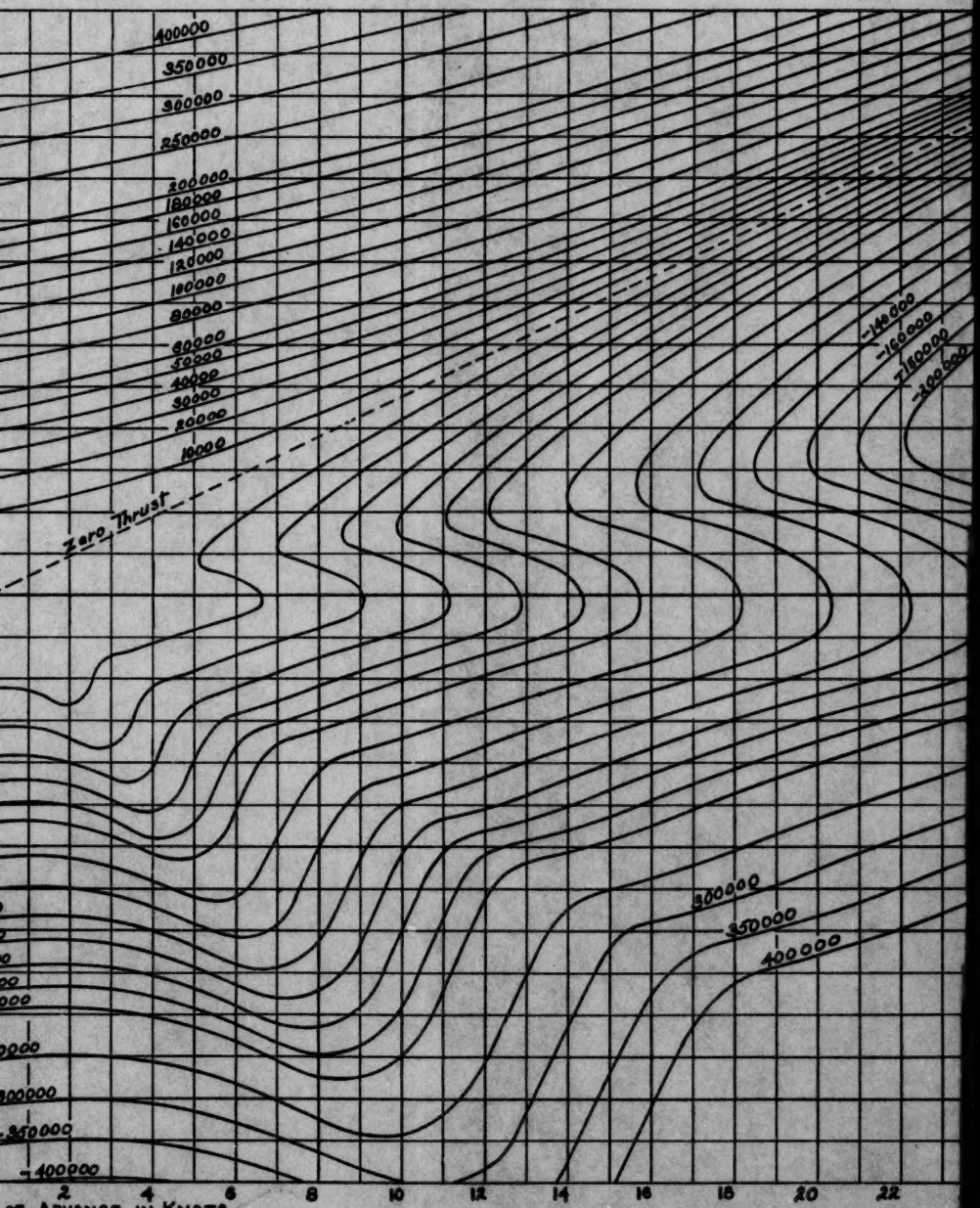
EXPRESSED IN POUNDS FOR ONE PROPELLE
EXPERIMENTS WITH MODEL PROPELLER No. 285
THAT LAW OF COMPARISON HOLDS FULLY

DIAMETER PROPELLER = 18'-3" P



THE U.S.S. DELAWARE PROPELLER

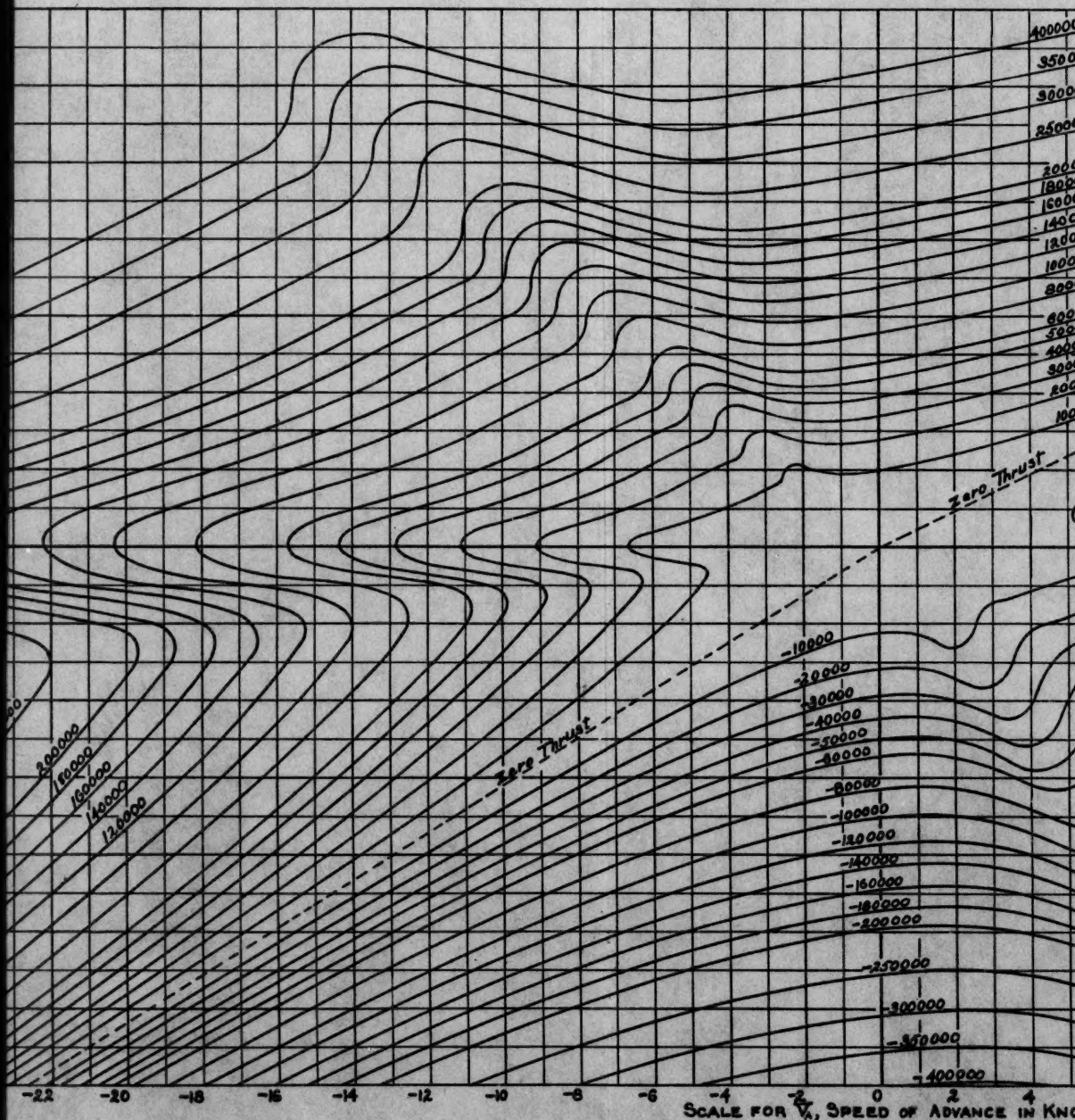
PROPELLER. DERIVED FROM
LER No. 265 AND BASED ON ASSUMPTION
ULLY
8'-3" PITCH-19'-9"



CONTOUR CURVES OF THRUST OF THE U.S.S. DELAW

EXPRESSED IN POUNDS FOR ONE PROPELLER. DERIVED
EXPERIMENTS WITH MODEL PROPELLER No. 285 AND BASED
THAT LAW OF COMPARISON HOLDS FULLY

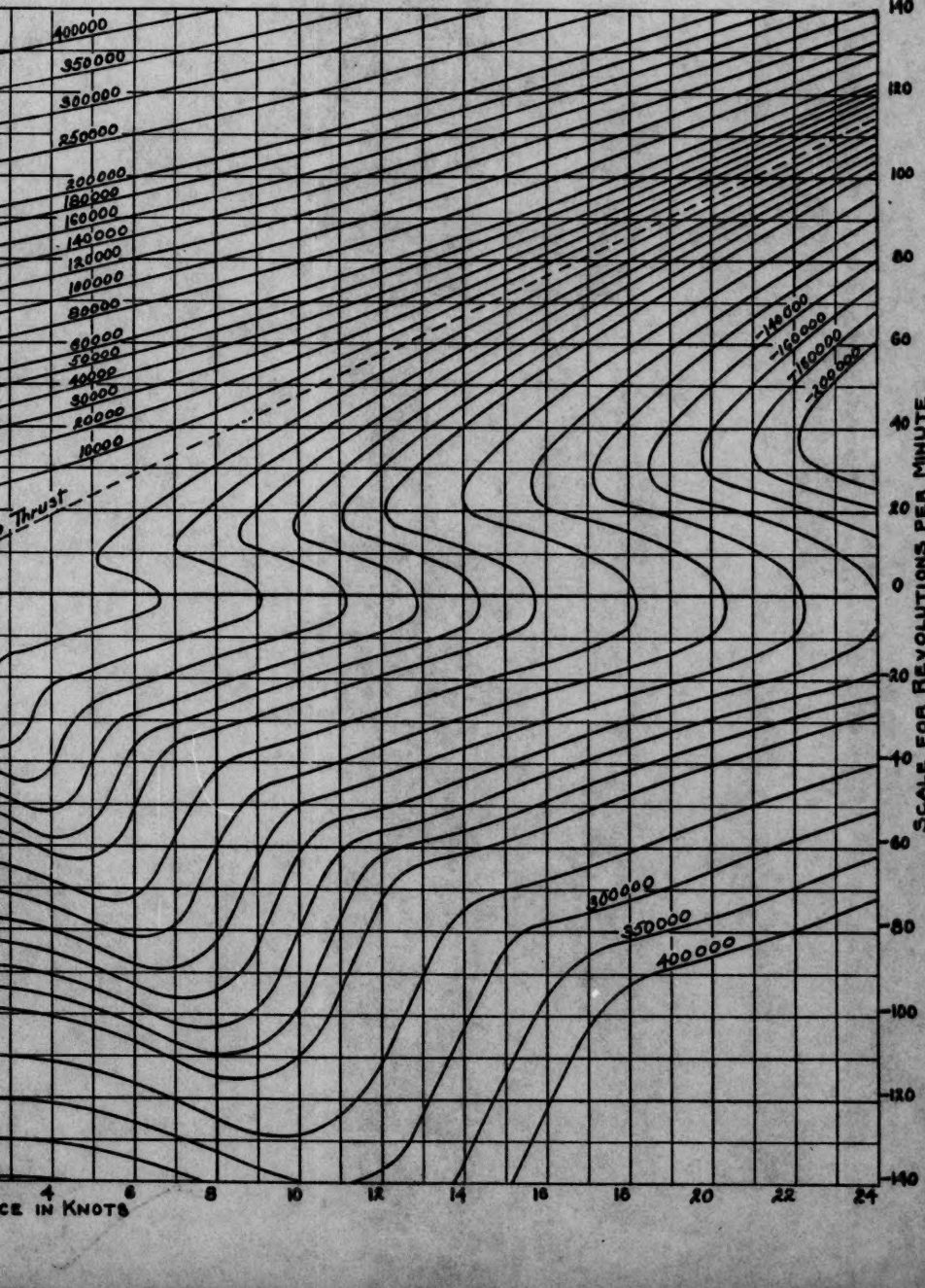
DIAMETER PROPELLER = 18'-3" PITCH = 19'-9"



S. DELAWARE PROPELLER

R. DERIVED FROM
AND BASED ON ASSUMPTION

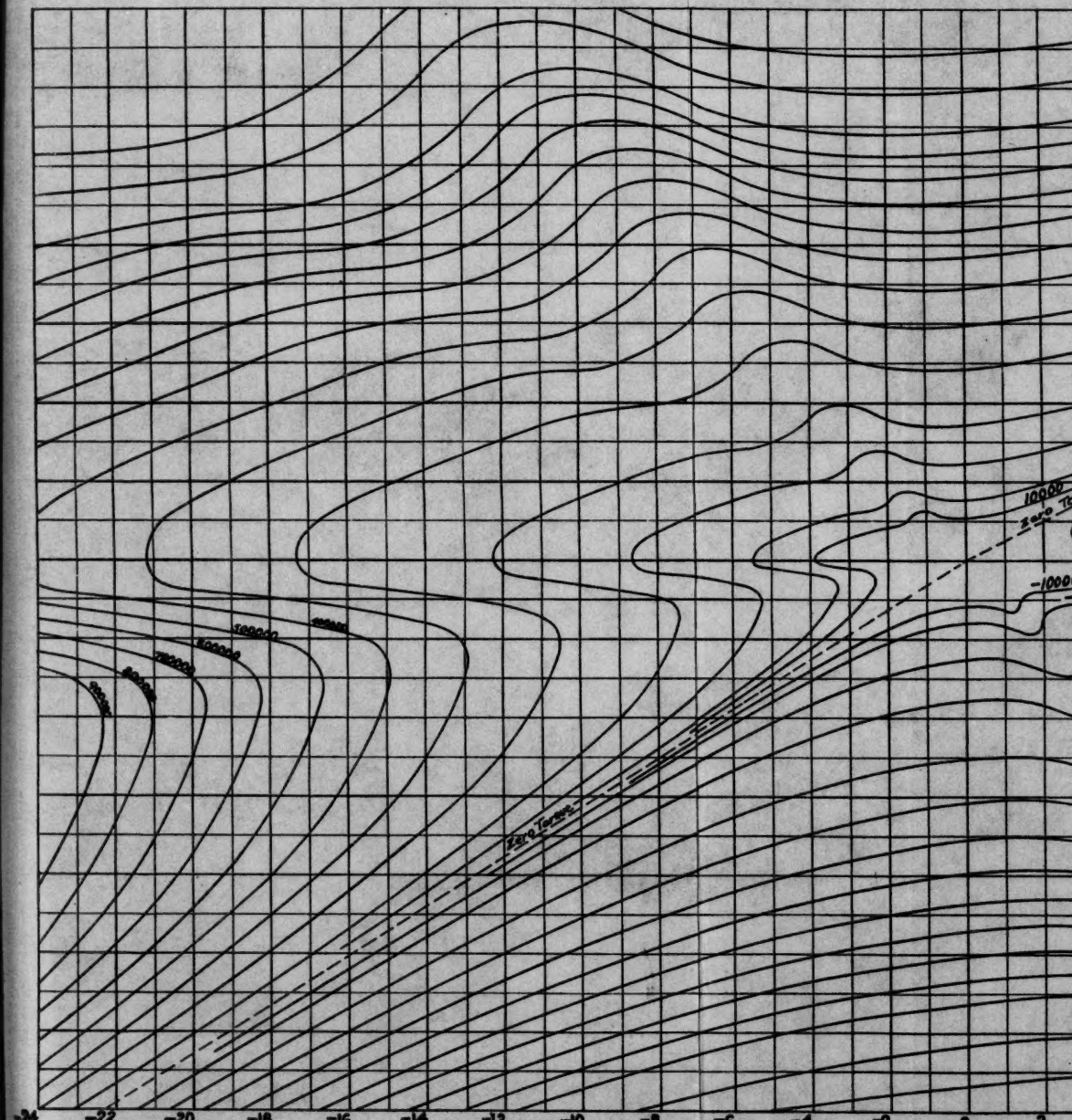
TCH=19'-9"



CONTOUR CURVES OF TORQUE OF THE U

EXPRESSED IN POUND FEET FOR ONE PROPEL
EXPERIMENTS WITH MODEL PROPELLER No.285 A
THAT LAW OF COMPARISON HOLDS FULLY

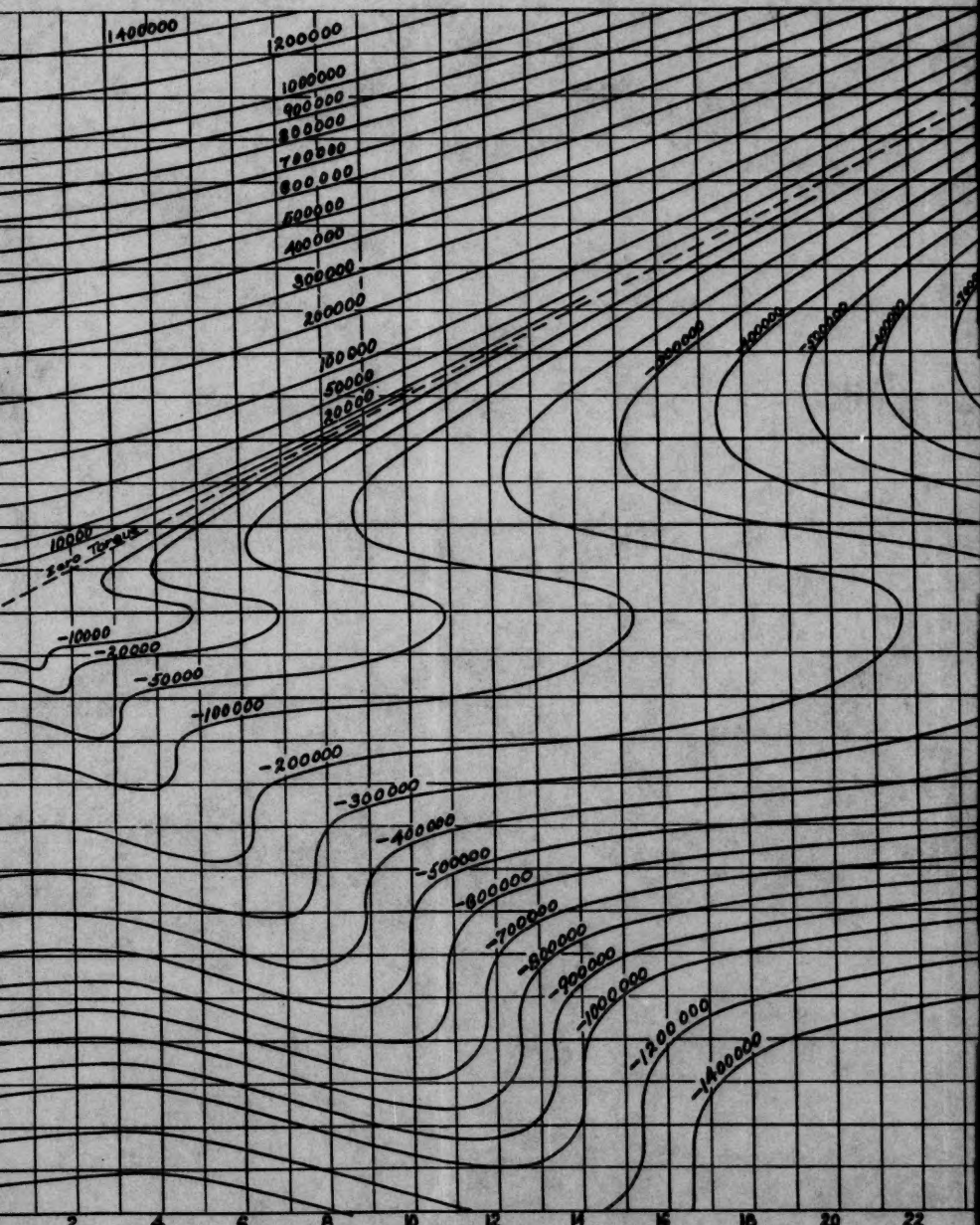
DIAMETER PROPELLER = 18'-3" PITCH



SCALE FOR V_A, SPEED OF A

OF THE U.S.S. DELAWARE PROPELLER.

NE PROPELLER. DERIVED FROM
R No. 285 AND BASED ON ASSUMPTION
LY
PITCH=19'-9"

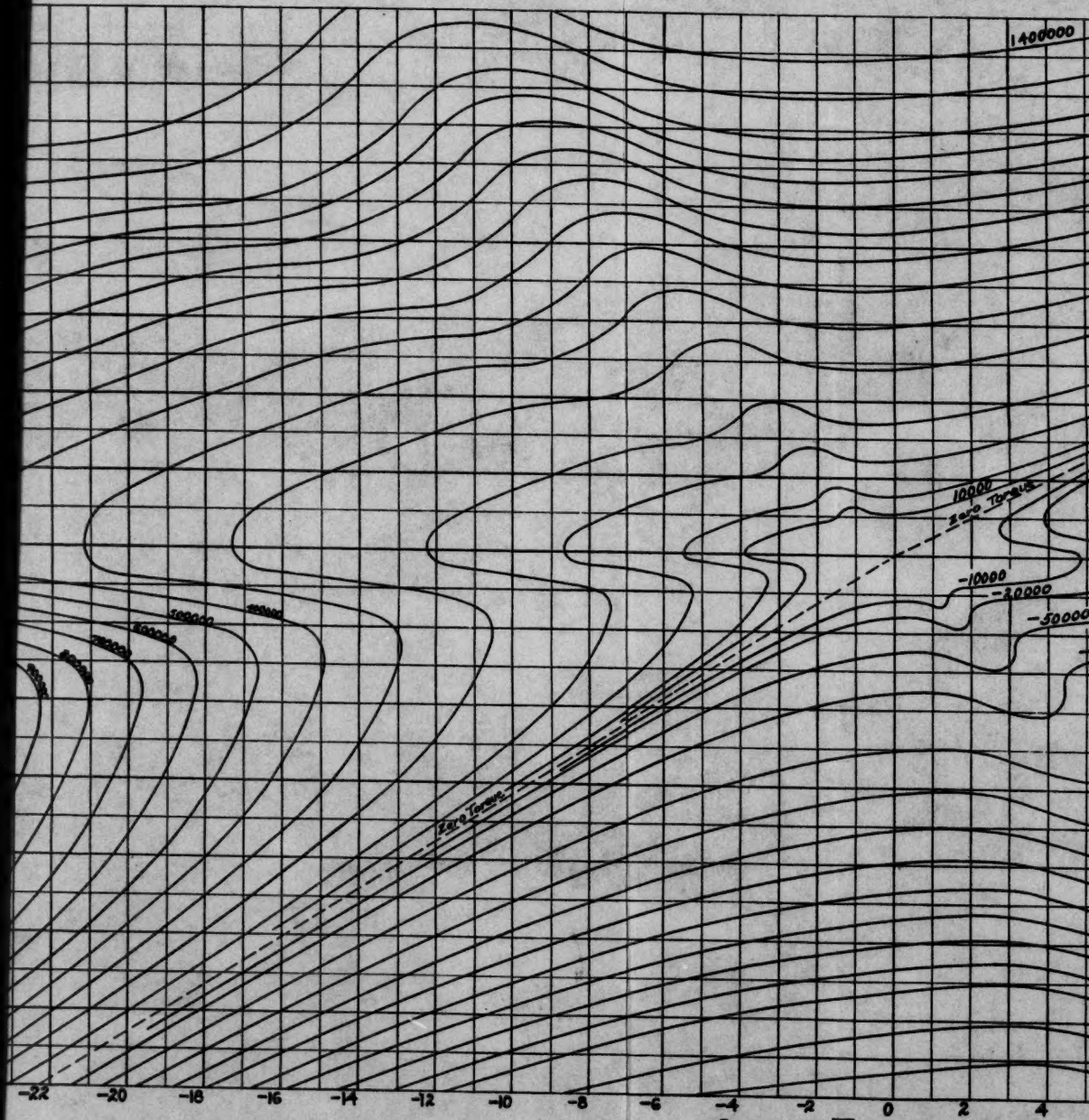


EED OF ADVANCE IN KNOTS

CONTOUR CURVES OF TORQUE OF THE U.S.S. DE

EXPRESSED IN POUND FEET FOR ONE PROPELLER. DERI
EXPERIMENTS WITH MODEL PROPELLER No.285 AND BASED
THAT LAW OF COMPARISON HOLDS FULLY

DIAMETER PROPELLER = 18'-3" PITCH=19'-9"

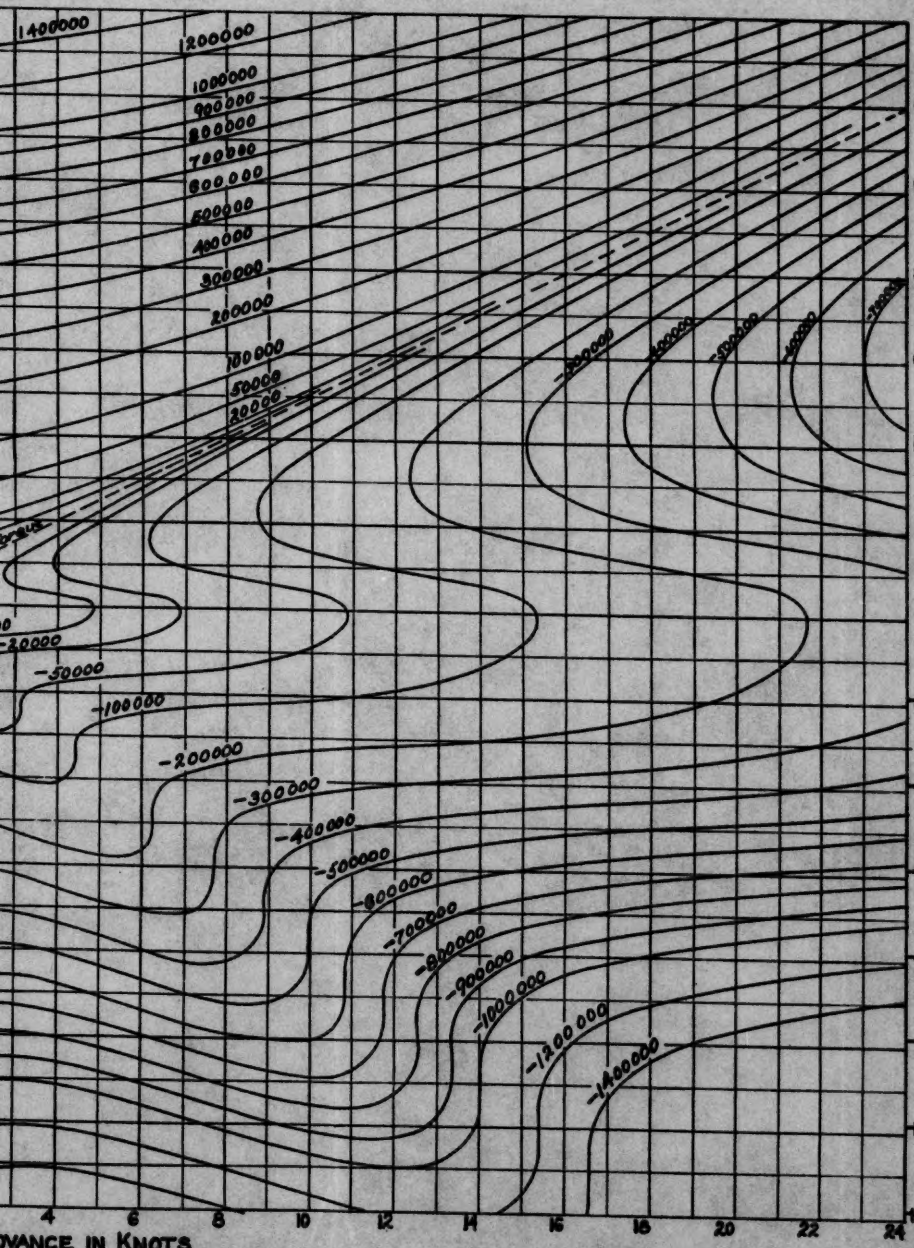


SCALE FOR V_A, SPEED OF ADVANCE IN

U.S.S. DELAWARE PROPELLER.

LLER. DERIVED FROM
AND BASED ON ASSUMPTION

H=19'-9"



While this equation is derived from model tank curves of a battleship, it is believed to be sufficiently accurate for all types of ships. It should be remembered that we are not dealing with a screw working under normal conditions. To check the accuracy of the equation, many different types of ships have been used.

From the equations deduced for R and T we can obtain the total force exerted to stop the ship. We shall have—

$$T + R = R_{FP}\left[\ 1.1C + \left(\frac{v}{v_{FP}}\right)^2\ \right] + R_{FP} \times \left(\frac{v}{v_{FP}}\right)^2$$

$$= R_{FP}\left[\ 1.1C + 2\left(\frac{v}{v_{FP}}\right)^2\ \right]$$

Any force acting on a given mass produces an acceleration according to the classic formula—

$$F = m\,a$$

Here we have—

$$F = R + T = R_{FP}\left[\ 1.1C + 2\left(\frac{v}{v_{FP}}\right)^2\ \right]$$

$$M = \frac{W}{g}$$

$$a = \frac{dv}{dt}$$

Therefore—

$$R_{FP}\left[\ 1.1C + 2\left(\frac{v}{v_{FP}}\right)^2\ \right] = \frac{W}{g} \times \frac{dv}{dt}$$

$$\text{or } dt = \frac{W}{2gR_{FP}} \times \frac{dv}{.55C + \left(\frac{v}{v_{FP}}\right)^2}$$

$$\text{and } t = \frac{W}{2gR_{FP}} \int_{v}^{v_1} \frac{dv}{.55C + \left(\frac{v}{v_{FP}}\right)^2}$$

$$t = \frac{W}{2gR_{FP}} \times \frac{1}{\sqrt{\frac{.55C}{v_{FP}^2}}} \tan^{-1} v\sqrt{\frac{1}{v_{FP}^2 \times .55C}} \Bigg]_{v}^{v_1}$$

$$= \frac{Wv_{FP}}{2gR_{FP}\sqrt{.55C}} \tan^{-1} \frac{v}{v_{FP}}\sqrt{\frac{1}{.55C}} \Bigg]_{v}^{v_1}$$

If we substitute for W and v_{FP}, the corresponding values of D and V_{FP}, we have—

$$t = \frac{58.8\ D\ V_{FP}}{R_{FP}\sqrt{.55C}} \tan^{-1} \frac{V}{V_{FP}\sqrt{.55C}} \Bigg]_{v}^{v_1}$$

Now, if we bring the ship to a stop, then we shall have for the limits, V_1 and 0, and therefore—

$$t = \frac{58.8\ D\ V_{FP}}{R_{FP}\sqrt{.55C}} \tan^{-1} \frac{V_1}{V_{FP}\sqrt{.55C}}$$

To obtain the equation for head-reach, we have—

$$dH = vdt$$

We can integrate this equation, and we shall obtain—

$$H = \frac{49.7\ D\ V_{FP}^2}{R_{FP}} \log_e \left[1 + \left(\frac{V}{V_{FP}}\right)^2 \times \frac{1}{\text{Constant} \times C}\right]_{V}^{V_1}$$

It has been found by calculating the head-reach of many ships that the constant in this equation differs from the one used in the equation for *t*; this shows that the equation used for obtaining the value

of T is not absolutely accurate. Hence a constant can be used in the equation for head-reach which will give equally accurate results as those obtained by the t equation; this value is .4 instead of the .55 used before. Substituting this value, we have—

$$H = \frac{49.7\ D\ V_{FP}^2}{R_{FP}} \log_e \left[1 + \left(\frac{V}{V_{FP}}\right)^2 \times \frac{1}{.4C} \right]_V^{V_1}$$

If we bring the ship to a stop, the limits are V_1 and 0, and we have—

$$H = \frac{49.7\ D\ V_{FP}^2}{R_{FP}} \log_e \left[1 + \left(\frac{V_1}{V_{FP}}\right)^2 \times \frac{1}{.4C} \right]$$

The next condition of stopping to be considered will be that of a ship with propellers held stationary. Referring again to our charts of torque and thrust, we find that the resistance of the propellers varies as the square of the speed of the ship and is equal to $1.04R_{FP}$ at full speed. The total force for stopping the ship will be—

$$R + T = R_{FP} \times \left(\frac{V}{V_{FP}}\right)^2 + 1.04\ R_{FP} \times \left(\frac{V}{V_{FP}}\right)^2 = 2.04\ R_{FP} \times \left(\frac{V}{V_{FP}}\right)^2$$

The time for reducing to any speed will be—

$$t = \frac{W}{gR_{FP}} \int_V^{V_1} \frac{dv}{2.04 \left(\frac{V}{V_{FP}}\right)^2} = \frac{-\ 57.8\ D\ V_{FP}^2}{R_{FP}} \times \frac{1}{V} \Bigg]_V^{V_1}$$

Putting in the limits of V_1 and V, we have—

$$t = \frac{57.8\ D\ V_{FP}^2}{R_{FP}} \left[\frac{1}{V} - \frac{1}{V_1} \right]$$

For head-reach, we shall have—

$$H = \frac{W}{gR_{FP}} \int_{V}^{V_1} \frac{vdv}{2.04 \left(\frac{V}{V_{FP}}\right)^2} = \frac{97.7\ D\ V_{FP}^2}{R_{FP}} \log_e V \Big]_{V}^{V_1}$$

Putting in the limits of V_1 and V, we have—

$$\text{or } H = \frac{97.7\ D\ V_{FP}^2}{R_{FP}} \log_e \left(\frac{V_1}{V}\right)$$

For the third condition, we have the screws revolving freely, without power. From our torque and thrust charts, we shall find that the resistance of the propellers will vary as the square of the speed of the ship and is equal to .34 R_{FP} at full speed.

The equations for this condition will be of exactly the same form as those for the second condition except that we shall have to substitute 1.34 R_{FP} for total resistance instead of 2.04 R_{FP}. Therefore we shall have—

$$t = \frac{88\ D\ V_{FP}^2}{R_{FP}} \left[\frac{1}{V} - \frac{1}{V_1}\right]$$

$$\text{and } H = \frac{148.7\ D\ V_{FP}^2}{R_{FP}} \log_e \left(\frac{V_1}{V}\right)$$

The above equations have been tested by using the data on backing from all types of ships—merchant vessels, battleships, destroyers and cruisers and it has been found that the error is less than 10 per cent in all cases. Where the data are known to be accurate, the error has been remarkably small, on the order of 2 or 3 per cent. It will be appreciated that considerable judgment must be used in applying these equations. First, the torque actually used must be known; second, the type of engine must be taken into consideration in determining the equations to be used for the period of time used

to reverse the engines. For example, a direct connected Diesel engine will come to rest very quickly, owing to its high friction load, and a relatively large time will be required to get the engine into reverse; of this total time, we can see that most of it is spent with the screws stationary. But with a geared turbine, say, on a destroyer, most of the time for reversal will be used up with the screws still going in the ahead direction; this is especially important because, with this type of ship, this period of time is usually greater than that required to bring the ship to a stop after the turbines are reversed. Therefore, for this type of engine, during the period of engine reversal we must choose a constant for the equation somewhere between that for propellers stationary and that for propellers revolving freely. In all cases, the total time to bring the ship to a stop must be calculated in two steps, one for the period used to reverse the engines and the second for the time used with engines actually backing.

It is desirable to show how the equations are affected by changes in the torque constant.

First let us simplify the conditions as much as possible; assume that backing begins instantaneously—in other words, $V_1 = V_{FP}$; and let K represent the part of the equation fixed by the ship and engines constants. Then

$$t = \frac{K}{\sqrt{.55C}} \tan^{-1} \frac{1}{\sqrt{.55C}}$$

$$\text{If } C = .5 \text{ then } t = \frac{K}{.524} \tan^{-1} \frac{1}{.524} = \frac{K}{.524} \times \frac{62.37}{180} \times \pi = 2.08K$$

$$\text{If } C = 1.2 \text{ then } t = \frac{K}{.812} \tan^{-1} \frac{1}{.812} = \frac{K}{.812} \times \frac{50.7}{180} \times \pi = 1.09K$$

Thus we see what a tremendous effect changes in torque produce. Of course, the actual difference is never this great because there is always a considerable time used up in reversing the engines and therefore the reduction in time is not so great a proportion of the

total; and the greater the time taken to reverse the engines, the less important will be the torque used after reversal of the propellers.

Let us see the effect of torque on head-reach. Using the same assumptions as before, we have—

$$H = K_1 \log_e \left[1 + \frac{1}{.4C}\right]$$

$$\text{If } C = .5, \text{ then } H = K_1 \log_e \left[1 + \frac{1}{.2}\right] = 1.7918K_1$$

$$\text{If } C = 1.2, \text{ then } H = K_1 \log_e \left[1 + \frac{1}{.48}\right] = 1.1249K_1$$

We see that head-reach is also greatly affected by the torque but not to as great a degree as the time, during the period when the propellers are in reversal; of course, head-reach will be more affected than the time by the torque used to bring the engines to rest.

We shall now solve a few problems to show how the equations are used and how assumptions are made for various types of machinery. First we shall take the U. S. S. *Delaware*. Here we have—

$D = 20{,}000$ tons

$V_{FP} = 21$ knots

E.H.P. $= 13{,}350$

$$R_{FP} = \frac{326 \times 13350}{21} = 206800 \text{ pounds.}$$

The time required to reverse the engines was only 14 seconds. It will be sufficiently accurate for this short period to assume the propellers were revolving freely ahead during all of this period. Therefore—

$$t = 14 = \frac{88 \times 20000 \times 21^2}{206800}\left(\frac{1}{V} - \frac{1}{21}\right)$$

and V = 19.5 knots.

Also—

$$H = \frac{148.7 \times 20000 \times 21^2}{206800} \log_e \frac{21}{19.5} = 465 \text{ feet.}$$

For the remainder of the stopping period we find that the engines developed an average torque of 117 per cent as shown by the R.P.M. and S.H.P. developed. Therefore we have—

$$t = \frac{58.8 \times 20000 \times 21}{206800 \sqrt{.55 \times 1.17}} \tan^{-1} \frac{19.5}{21 \sqrt{.55 \times 1.17}}$$

$$= 128 \text{ seconds}$$

total time = 14 + 128 = 142 seconds = 2 minutes — 22 seconds.

The actual time was 2 minutes — 21 seconds.

The head-reach during the second part of the period will be—

$$H = \frac{49.7 \times 20000 \times 21^2}{206800} \log_e \left[1 + \left(\frac{19.5}{21} \right) \times \frac{1}{.4 \times 1.17} \right]$$

$$= 2220 \text{ feet}$$

total H = 2220 + 465 = 2685 feet = 895 yards.

For our next example, we shall take a merchant vessel fitted with Diesel engines. Here we have—

D = 26,000 tons

V_{FP} = 17.5 knots

E.H.P. = 10,000

The speed at the time of reversal was 15 knots and 30 seconds were required to reverse the engines. For this type of engine it will be sufficiently accurate to assume the propellers were stationary during the reversal period since this would be true for the greater part of it.

We shall have—

$$R_{FP} = \frac{326 \times 10000}{17.5} = 186000 \text{ pounds.}$$

$$\text{and } t = 30 = \frac{57.8 \times 26000 \times 17.5^2}{186000} \left[\frac{1}{V} - \frac{1}{15}\right]$$

or V = 12.7 knots.

$$\text{and } H = \frac{97.7 \times 26000 \times 17.5^2}{186000} \log_e \left[\frac{15.0}{12.7}\right] = 692 \text{ feet.}$$

For Diesel engines, C will usually vary from .8 to 1; in this case we can assume a value of 1 as the trials were made under test conditions with the test prearranged. Therefore during the backing period we have—

$$t = \frac{58.8 \times 26000 \times 17.5}{186000 \sqrt{.55}} \tan^{-1} \frac{12.7}{17.5 \sqrt{.55}} = 152 \text{ secs.}$$

total time = 30 + 152 = 182 = 3 minutes — 2 seconds.

The actual time was 3 minutes — 15 seconds.

Error = 7.15 per cent.

The head-reach during the same period was—

$$H = \frac{49.7 \times 26000 \times 17.5^2}{186000} \log_e \left[1 + \left(\frac{12.7}{17.5}\right)^2 \times \frac{1}{.4}\right]$$

= 1790 feet.

Total H = 692 + 1790 = 2482 feet.

Actual H was 2280 feet.

Error = 8.15 per cent.

On this same ship, it was desired to know what speed would be reached after 3 minutes, with engines stopped. The displacement at

the time was 22,000 tons. Due to some weeks out of dock the horsepower required was about the same as that for normal conditions of displacement. The speed at the beginning of the period was 15.75 knots. Therefore, we have—

$$t = 180 = \frac{57.8 \times 22000 \times 17.5^2}{186000}\left[\frac{1}{V} - \frac{1}{15.75}\right]$$

or $V = 6.7$ knots.

One more problem will complete the illustration of the various ways of choosing the "time" constant. This will be a destroyer. Here we have—

$D = 2139$

$V_{FP} = 39.4$

E.H.P. = 32,250.

Therefore—

$$R_{FP} = \frac{326 \times 32250}{39.4} = 267000 \text{ pounds.}$$

The available backing torque (after reversal) was estimated to be 50 per cent of the full load torque. The time required for reversal was 42 seconds. Most of this would be consumed with propellers revolving ahead, so we can say—

$$t = 42 = \frac{88 \times 2139 \times 39.4^2}{267000}\left[\frac{1}{V} - \frac{1}{39.4}\right]$$

or $V = 15.65$ knots

and

$$H = \frac{148.7 \times 2139 \times 39.4^2}{267000} \log_e \left(\frac{39.4}{15.65}\right) = 1710 \text{ feet.}$$

For the remainder of the stopping period we have—

$$t = \frac{58.8 \times 2139 \times 39.4}{267000\sqrt{.275}} \tan^{-1} \frac{15.65}{39.4\sqrt{.275}} = 23 \text{ secs.}$$

Total $t = 42 + 23 = 67$ seconds.
Actual time was 65 seconds.
Error = 3 per cent.
Also—

$$H = \frac{49.7 \times 2139 \times 39.4^2}{267000} \log_e \left[1 + \left(\frac{15.65}{39.4}\right)^2 \times \frac{1}{.2}\right] = 360 \text{ feet.}$$

Total $H = 1710 + 360 = 2070 = 690$ yards.
Actual H = 717 yards.
Error = 3.9 per cent.

While the formulae used in developing the equations in this paper are based on model tank results, it has been possible to check them by other methods. For example, the case of a stationary propeller can be solved by considering the propeller as a plane dragged through the water at an angle and it will be found to give results very close to the model tank figure of 104 per cent. In the case of a "freely revolving" propeller, it has been possible to check the figure of 34 per cent by considering the resistance of the propeller to be similar to that of an appendage. This method was used in the paper published in 1916 and the figure obtained was about 30.2 per cent. That this figure is somewhat too small is shown by the fact that the calculations obtained from it give a "time of stopping" somewhat larger than the actual time. The figure of 34 per cent would check the actual results very closely. These checks give me confidence to believe that the equations deduced must be reasonably accurate for full-sized propellers and ships. Only a few sample calculations have been given in the paper but the backing data from many other ships have been used to check the formulae and the results check their accuracy within less than 10 per cent and it is believed that accurate results can be obtained for all types of ships, provided that accurate data are available.

FIFTY YEARS OF NAVAL ENGINEERING IN RETROSPECT.

PART III.

1908-1921.

By Herbert M. Neuhaus, Member.*

In marking its golden anniversary of existence, the American Society of Naval Engineers scans the panorama of its past in this series of four articles. Created in October, 1888, shortly after the birth of the "New Navy" of the United States, the Society almost immediately began the dissemination of information of interest in the form of its Journal. *This* Retrospect, *briefed and abstracted from the* Journals *of the past, tells the story of the change from double expansion to triple expansion engines; from the old horizontal and vertical engines to the giant vertical inverted four-cylinder triple expansion engine mounted in the U. S. S. Oklahoma; the change from fire-tube boilers to water-tube boilers; the appearance of the steam turbine and its displacement of the reciprocating engine; the appearance and development of the modern submarine; and the creation of the all big gun battleships, popularly called the Dreadnoughts from their prototype. That these changes have occurred in less than a half century is nothing short of amazing when one considers the centuries of possible development that had gone before. If mechanical developments have been outstanding, electrical progress has been more so. In the field of communication, wireless telegraphy has come into its own, the telephone is in common everyday use on shipboard, and the use of electrical controls plays an ever-increasing part. In short, the United States Navy by 1908 has become a gigantic laboratory for machinery experiments of every kind on a full scale.*

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The record from 1898 to 1908 closed with the steam turbine the outstanding heavyweight challenger to the triple expansion engine, which had held undisputed sway in the marine propulsion field for two decades. It is small wonder then that the advocates of the reciprocating steam engine were overly enthused over the discomfiture of the newcomer when follow-up trials and service operation gave to the incumbent a decided advantage in economy and efficiency. As stated before, the contrast was very marked, for in a comparison of the *Chester, Salem,* and *Birmingham* economy of propulsion at speeds up to 20 knots, the reciprocating engined ship was found superior to the vessel fitted with Parsons turbines and up to 21 knots superior to the Curtis turbined vessel. Though this may not appear important to the uninitiated or to the merchant mariner who is accustomed to pushing his vessel at almost its maximum speed; to the naval engineer, most of whose cruising was done at much lower speeds than the maximum, economy was vital. Continued cruising under service conditions also demonstrated economy in maintenance, reliability, and ease of repair; the reciprocating engine again winning handily over its opponents. In defense of the newcomer may be cited the much longer experience of engineers with reciprocating engines; the same holding true to a lesser degree in comparing the Parsons turbine with the Curtis.

The story of the comparative trials of the three aforementioned cruisers holds almost the same degree of interest that the Navy fuel oil report did some years before. A description of these comparative trials which were made over a nine months period covers over one hundred pages in the August, 1910, issue of the JOURNAL. Special water measuring tanks had been built into each ship and a series of six distinct tests on each vessel was made to give as complete a comparison as possible. An indication of the economy of the *Birmingham's* reciprocating engines is indicated by the water rates at ten knots, the total water per hour for the *Birmingham* being 21,988 pounds, for the *Chester* 25,492 pounds, and 30,182 pounds for the *Salem.* Other objections to the turbine were found in the extra weight necessary to provide backing power as compared to the reciprocating engine, which required but little additional for full backing power. Even with the provision of special backing features in the turbine only forty per cent of the ahead power was

developed in going astern. However, the turbine did possess a far greater overload capacity than the reciprocating engine, most of early installations exceeding the generating capacity of the boilers. Following the *North Dakota* (Figure 1) and the *Delaware*, actually our first *Dreadnoughts* so planned, the *Florida, Utah, Arkansas,* and *Wyoming* followed in rapid succession. All were direct drive turbine installations of four shafts each. At the time of this writing the latter three are still in existence doing service with the Fleet, though in a much modified form.

A brief description of the *North Dakota's* engineering plant will serve as an illustration of the four battleships which followed her, although these latter were increasingly larger in size. Her contract price of $4,377,000, exclusive of side armor, armor, and ordnance, is interesting in comparison with present day battleship quotations, which are approximately ten times greater. A speed of 21 knots was specified and was exceeded by 0.83 knots on a trial displacement of 20,000 tons. A normal turbine capacity of 12,500 horsepower on each shaft was specified at 245 R.P.M. and 265 pounds pressure with 50 degrees superheat and 27 inches vacuum. On one trial run a maximum of 35,000 H.P. was indicated for both shafts.

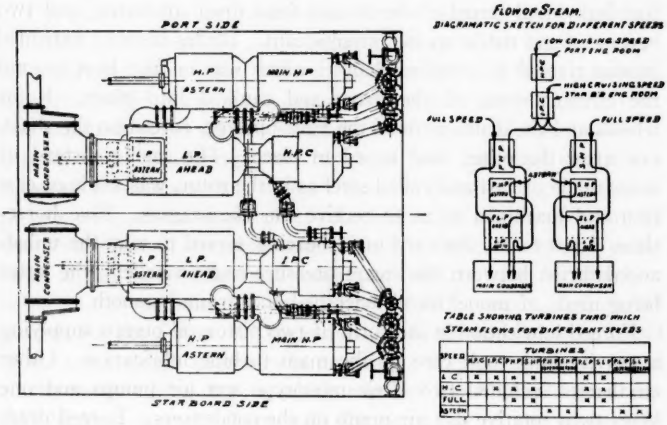
The turbines, which were of the Curtis type, were cylindrical in shape and twelve feet in diameter. Nine ahead stages consisting of five individual impulse wheels and four drum mounted, and two reverse stages made up the impulse unit. Blades were of extruded bronze riveted to a milled channel which was in turn bent around the circumference of the drum and caulked into place. Rotor wheels and the drum were of the built-up type, forced on the shaft, one after the other, and keyed in place. The casing instead of being made of cast and rolled steel as in the rotor, was made of cast iron and machined so as to receive the diaphragms. Five horseshoes fitted to the forward main bearing served to take the unbalanced thrust between the steam pressure and propellers, the latter being made of monel metal machined and ground smooth.

Forced lubrication in the form of two piston oil pumps supplying a gravity tank took care of the main turbine lubrication. Other auxiliaries included two Weir monotype wet air pumps and one Weir twin rotative dry air pump on the condensers. Forced draft was furnished by motor driven service blowers feeding to closed

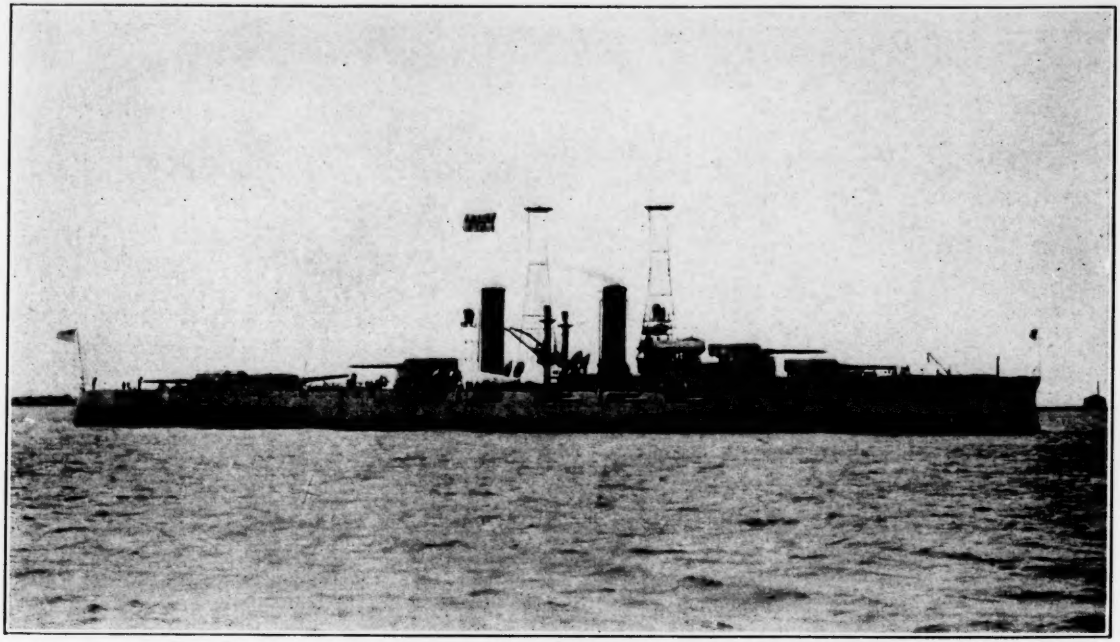
firerooms, the forward three firerooms each containing four Babcock and Wilcox water-tube boilers, and the after fireroom housing two boilers. Ashes from the fires were discharged over the side by means of Williamson ash hoists fitted to ventilator trunks or a Stone pneumatic ash and clinker expeller which crushed any clinker thrown into its hopper and by a compressed air arrangement discharged the ashes directly overboard. Allen dense air ice machines still formed the backbone of the refrigeration system and for fresh water, a 25,000 gallons per day pressure evaporator unit was installed.

On both the *North Dakota* and *Delaware* oil fuel was provided for use in conjunction with coal, the Schuette and Koerting system being used with three groups of burners to a furnace. Oil was drawn by pumps in each fireroom from storage tanks in the inner bottoms of the engine rooms, pumped to settling tanks in the firerooms and then by pressure through filters and heaters to the burners. Each oil storage compartment was provided with an expansion trunk.

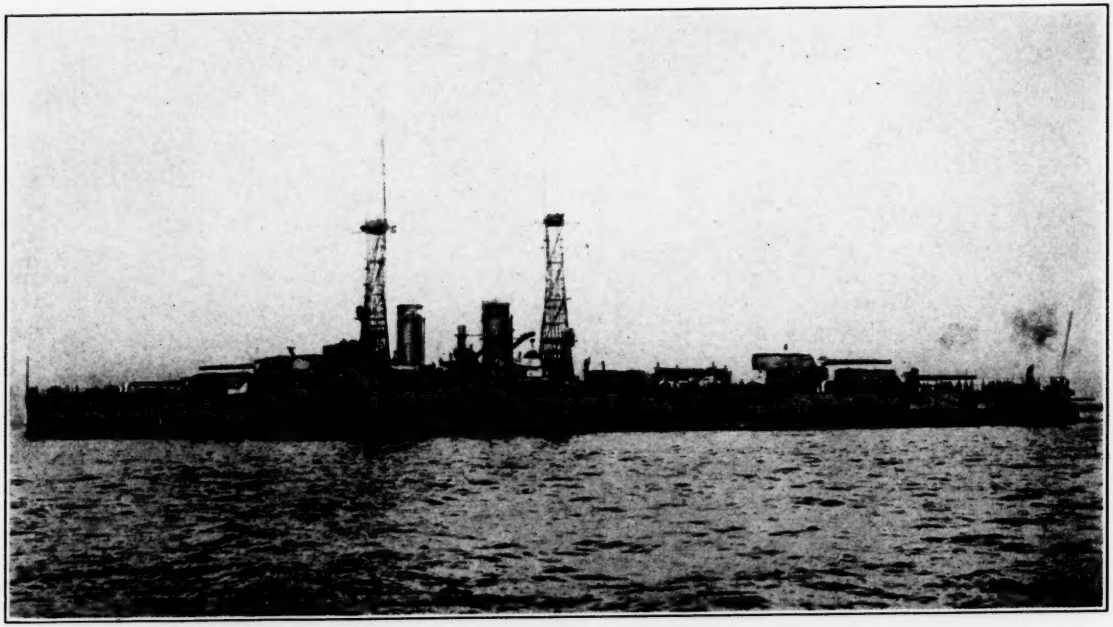
The *Florida* and *Utah* which followed were fitted with Parson's turbines on four shafts (Figure 2), the main high-pressure turbines being mounted outboard, and the high pressure cruising,



U.S.S. UTAH.
FIGURE 2.



U. S. S. "North Dakota."
Figure 1.

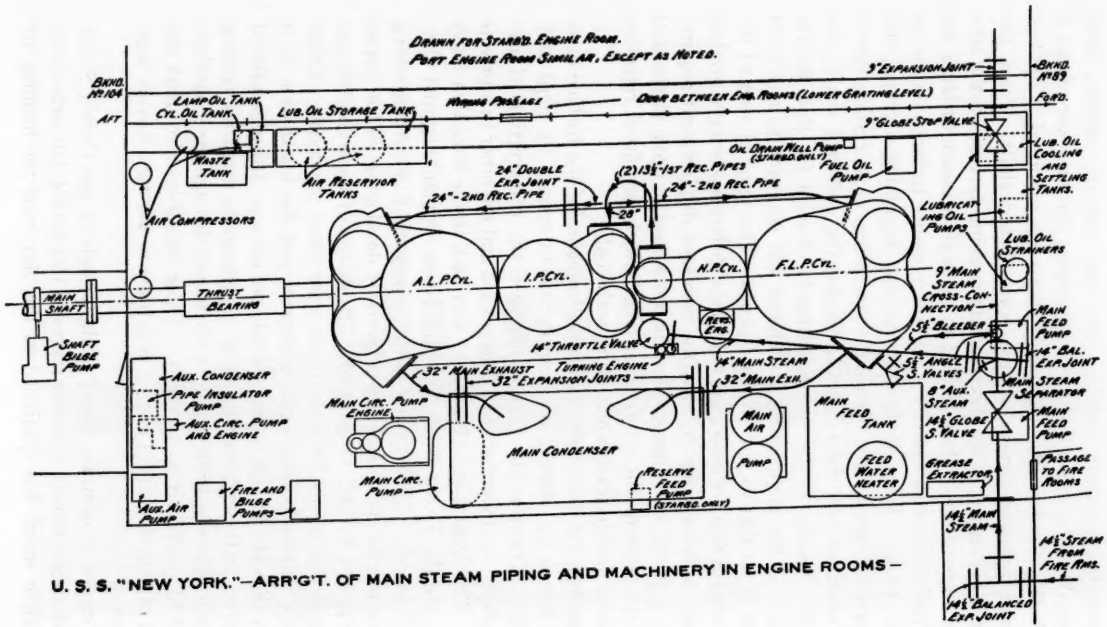


U. S. S. "New York."
Figure 3.

intermediate pressure cruising, and low pressure turbines being mounted on the inboard shafts. Reversing turbines were fitted to all shafts. At low cruising speeds steam was admitted to the high pressure cruising turbine on the port inboard shaft. From this point it exhausted to the intermediate cruising turbine on the starboard inboard shaft, then divided to the high pressure turbines and returned to the condensers via the low pressure turbines on the inboard shafts. To a young engineer just beginning a cruise, this arrangement must have been quite confusing, as at certain speeds the revolutions of the inboard exceeded the outboard shafts, the R.P.M. crossing as the speeds changed. Except for this, the remainder of the engineering installation did not vary to any great degree from that of the *North Dakota*. The same is true of the *Wyoming* which followed, the only large difference being a gradual increase in horsepower to meet the increased displacement requirements and the substitution of a Babcock and Wilcox mechanical atomizing system for oil fuel burning, which permitted retention of the burners in place while firing with coal.

However, the poor comparative performance of the turbine drive ships forced the Bureau of Engineering to retrace its steps temporarily. Congress, in 1910, authorized the construction of two battleships, one to be built in a Navy Yard and the other in a private yard. The *New York* (Figure 3) was built in the Brooklyn Navy Yard, and the *Texas* at the Newport News Shipbuilding and Drydock Company. Their motive power consisted of two reciprocating engines, one on each shaft and collectively developing 28,100 horsepower at 125 R.P.M. (Figure 4). The design of these engines was similar to that of the *Delaware*, built some years previously. Other than the return to reciprocating engines and the installation of a carbon dioxide refrigeration system, no unusual features offered themselves in the engineering plant. A change in magazine cooling was made whereby brine was now circulated through the magazines instead of cooled air as formerly. These two ships also mark the advent of fourteen-inch guns, of which ten in five twin turrets were supplied.

A feature of contrast found in the vessels of the United States Navy designed during the early stages of this period, but embodying a principle which has continued to this day, was the building of



U. S. S. "NEW YORK."—ARR'G'T. OF MAIN STEAM PIPING AND MACHINERY IN ENGINE ROOMS—

FIGURE 4.

ships for service beyond the seas. The resulting problem became a difficult one as it meant combining maximum cruising radius with ability to make speed required by tactical considerations. Destroyers were not exempt from these considerations. Admiral Cone, in a lecture before the War College, stated that their cruising radius should approximate that of the battleship fleet at a sustained speed of fifteen knots. A perennial problem arising at this time was the related design requirement to reduce steam consumption at fifteen knots in an endeavor to build up cruising radius. Several suggestions for attaining the desired result were put forward, but of these only two appeared worthy of note. The first was to replace the cruising turbines in a three-shaft installation by small high speed turbines connected to the low pressure turbine shafts through reduction gears and a clutch for disconnecting at high speeds and when backing. This small turbine took steam direct from the main boilers and exhausted at about atmospheric pressure to the main turbines.

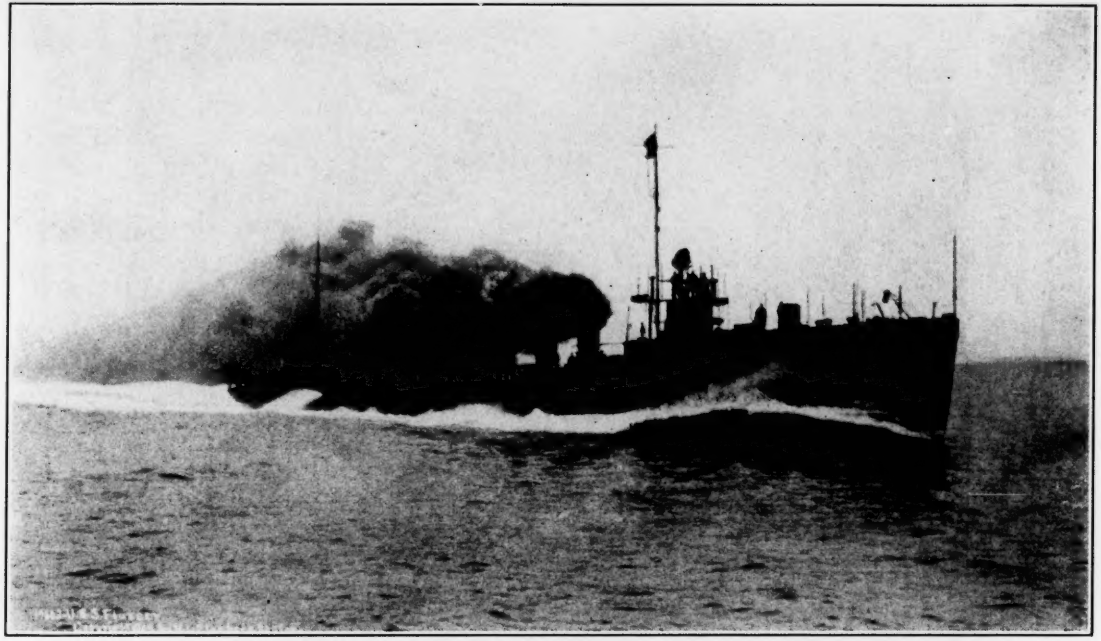
As another alternative, it was proposed to install a small reciprocating engine in place of the high speed turbine first mentioned and to connect the engine direct to a propeller. The engine would take its steam direct from the boiler and exhaust also to the regular main high pressure turbine. An economy gain of twenty per cent appeared possible with either of the two methods, together with the added advantage that any disability of the cruising elements would still leave a full powered plant. The two coal burning destroyers, *Flusser* (Figure 5) and *Reid,* delivered in 1910, were of the older type, but in them the high power developed to make them the first 30-knot destroyers in the United States navy, helped to emphasize the necessity for economy at lower speeds. Further performance trials were made on the newly commissioned destroyers forming the 7th Division of the Atlantic Torpedo Fleet in a run from Charleston, South Carolina, to Key West and back, where a total of 9500 miles was steamed at various speeds from eighteen to twenty-five knots.

A description of the destroyers built during the early years of this period will amplify the preceding paragraphs. Developed along similar lines to the battleship plants, the compactness of their hulls and the high powers necessary, made turbines an essential require-

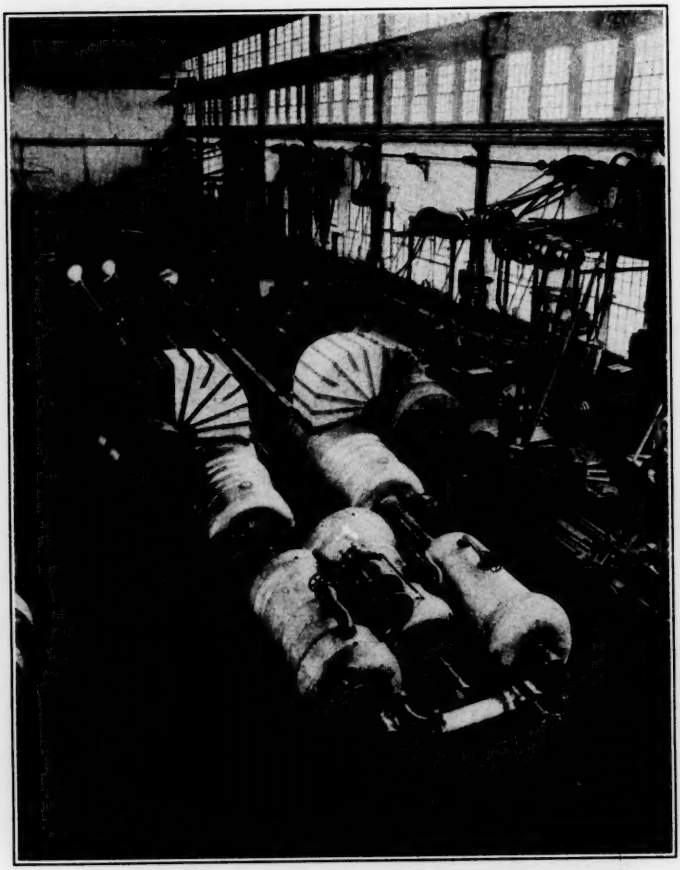
ment. The reciprocating engine for this type of ship had reached the peak of its capacity both in size and speed and further reductions in weight would seriously impair the safety of the engines. Consequently the *Smith* and *Lamson,* 700-ton destroyers, delivered in 1909 and 1910, were among the first five coal burning, turbine drive destroyers delivered to the Government. They were three-screw affairs (Figure 6), the *Smith* making a maximum speed of 31.901 knots on one run. No noticeable improvement over a reciprocating engine installation was noted, however, the trial board complaining about the crowded condition of the engine room auxiliaries.

The next ten destroyers authorized were slightly larger in that they were of 742 tons displacement, the old *Paulding* and *Drayton* being examples. Their contract price of $644,000 included $384,000 as the cost of machinery under the cognizance of the Bureau of Steam Engineering. In general, their layout resembled that of the preceding class, a three-shaft Parsons turbine combination. On the port shaft were the high pressure cruising turbines and a low pressure turbine. On the starboard shaft were the intermediate pressure cruising and another low pressure turbine. The center shaft was driven by the main high pressure turbine and by means of various piping arrangements different cruising combinations were possible. Only the outboard shafts were fitted for reversing, the center shaft idling when going astern. A maneuvering valve made possible ahead or astern motion by proper rotation of a single hand wheel. The most marked change in this group of destroyers was their oil burning equipment, coal from this time on being eliminated for destroyer fuel. Four Normand, return-flame, express type boilers furnished steam for propulsion. Other destroyers of the same group were fitted with Thornycroft, White-Forster, and Yarrow oil burning boilers, these latter three lacking tube baffling as in the Normand boiler. The Normand boiler differed in general appearance from later express boilers in that it was fitted with a steam dome at the front end of the steam drum.

A study of the records indicates that the *Roe,* of this same group of ten destroyers was the first oil burning destroyer delivered to the Navy. Of course, the others followed in rapid succession, each shipbuilder installing machinery of his preference. This explains



U. S. S. "FLUSSER."
FIGURE 5.

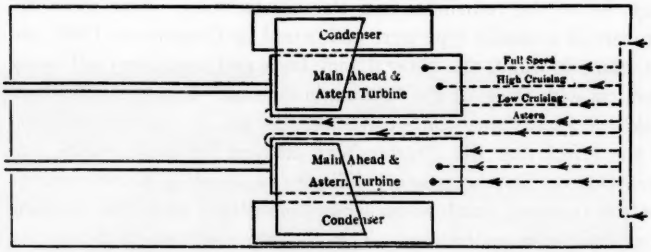


"Flusser" Turbines, Set Up in Shop.
Figure 6.

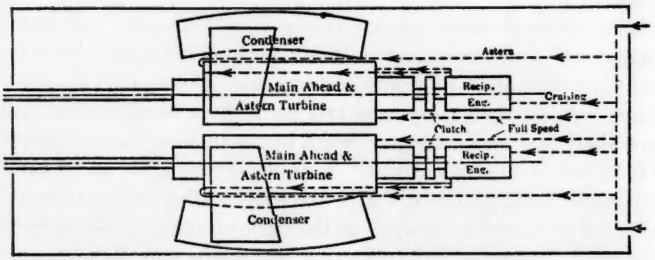
the various types of boilers found and the twin screw Curtis turbine arrangement found in the *Perkins* and *Sterett*, while the majority of the remainder had Parsons turbines. Five more destroyers of a similar type were authorized by Congress in 1909, and six more in 1910, the general hull lines and machinery all being identical with those of the 1908 authorization. One incident which makes it appear that some conditions do not change is a notation to the effect that the *Preston* was delayed for two months and twenty-three days because of difficulty in securing sound castings for the turbines, much work being condemned after the machine work had been undertaken. The *McCall*, *Burrows*, and *Ammen* also marked the use of Schutte & Koerting film oil coolers in destroyers, thus greatly improving the lubricating oil circulating systems.

In an effort to secure greater economy in destroyers, new combinations of prime movers were tried out and in the *Henley* was found a combination of Curtis turbines, and a compound reciprocating engine. Both the engine and the turbine were fitted to the same shaft, the engine being forward of the turbine, but connected to it by means of a jaw clutch. A similar combination was found on both port and starboard shafts, the reciprocating engine delivering 400 I.H.P. and exhausting to the eighteen-stage turbine which followed (Figure 7). At full power the engine was disconnected and the main steam was delivered direct to the turbine. (See Figures 7-10 for variations.)

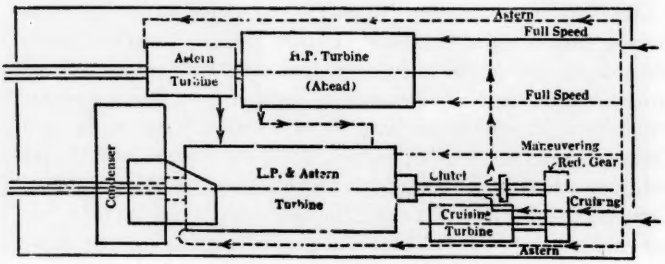
Dissatisfaction with the battleship propulsion units led to an investigation of other methods of main drive. However, before jeopardizing any of the main combatant units with an untried, unproved system, the Navy Department decided to make experimental installations on several auxiliary vessels (colliers) then to be built. Three reciprocating engined colliers, the *Mars*, *Vulcan*, and *Hector*, had been placed under contract construction to the Maryland Steel Company in 1908 and two more, the *Jason* and *Orion* in 1911. As new colliers were needed with the general increase of the Navy, they formed an ideal field for experimentation, particularly because of their protracted periods of cruising. The *Cyclops*, being the first of three additional colliers, was chosen for a twin-screw reciprocating engine drive.



Curtis Turbines: *Perkins, Sterett, Walke.* Zoelly Turbines: *Warrington*

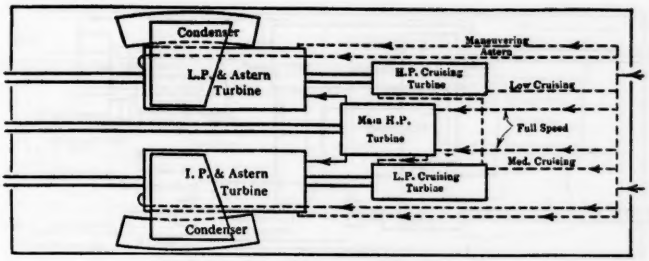


Curtis Turbines: *Downes, Duncan.* Cramp's Turbines: *Aylwin* Class (Seven Vessels)

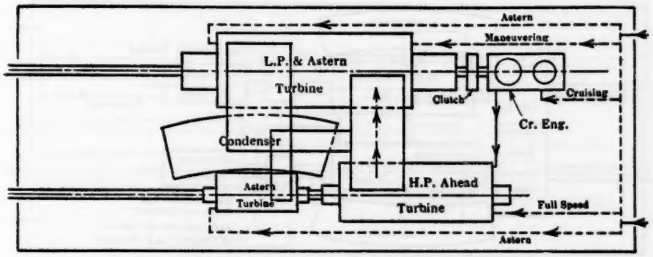


Parsons Turbines: *Conyngham, Porter, Wilkes*

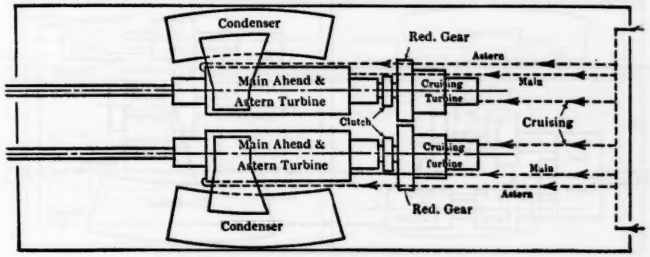
FIGURE 7.



Parsons Turbines: *Smith* Class (Twenty Vessels)

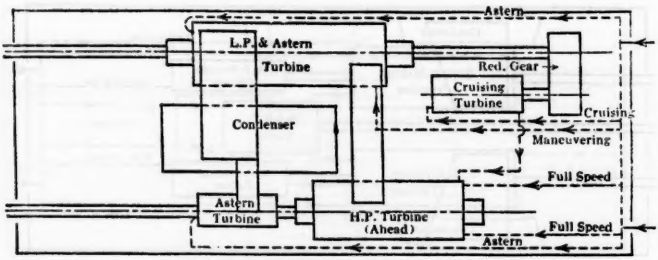


Parsons Turbines: *Cassin, Cummings, McDougall, Ericsson*

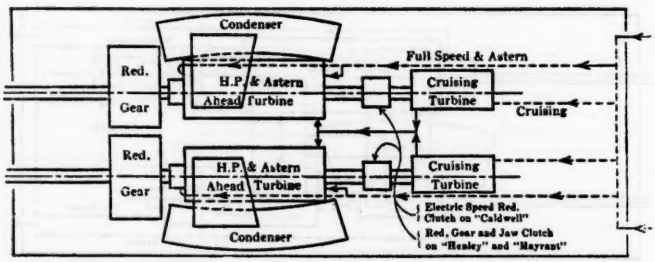


Curtis Turbines: *Cushing, Tucker, Sampson, Rowan*

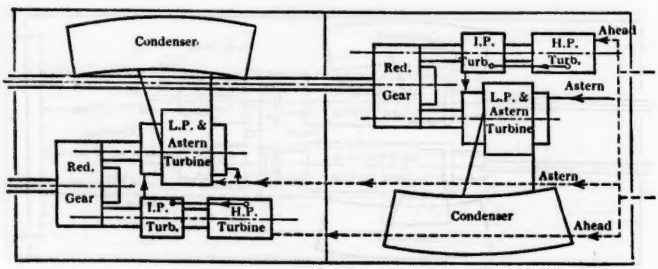
FIGURE 8.



Parsons Turbines: *Jacob Jones, Wainwright, Davis, Allen, Shaw*

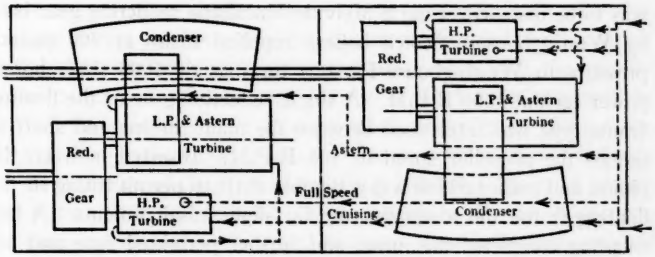


G. E. Curtis Turbines: *Caldwell.* Westinghouse Turbines: *Mayrant, Henley*

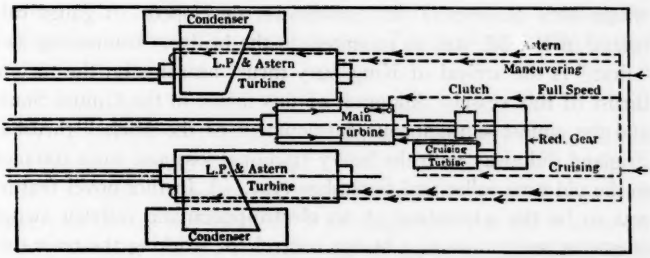


Curtis Turbines: 91 Vessels

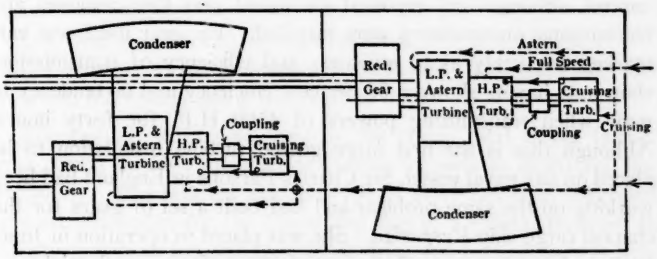
FIGURE 9.



Parsons Turbines: *Wadsworth* Class (89 Vessels). Westinghouse Turbines: *Wadsworth* Class (40 Vessels)



Parsons Turbines: *Conner, Stockton*



G. E. Curtis Turbines: 46 Vessels

FIGURE 10.

Built along the same hull and general lines was the *Neptune,* which followed in 1910. In the latter, full geared turbine drive was to be installed, using a Melville Macalpine reduction gear built by Westinghouse. Scotch boilers supplied steam at 200 pounds pressure to Westinghouse-Parsons turbines of 4000 shaft horsepower each at 1500 R.P.M. A single reduction gear of the floating frame type was interposed between the main turbine and shaft to reduce the propeller speed to 135 R.P.M. Inserted between the pinion and main turbine was a flexible shaft to permit tilting of the floating frame and to compensate for slight misalignments. A ball coupling completed the union and further permitted fore and aft motion of the pinion. Excessive motion in this direction was prevented by a dashpot. As the floating frame was of a hydraulic type, gauges connected to the cylinders balancing the frame gave readings which were convertible into horsepower developed. A gauge calibrated in R.P.M. was so mounted on the bridge. Interesting as a "first" is the arrival of Kingsbury thrust bearings on the turbine thrust of this vessel. Adoption of this thrust in the United States and the almost simultaneous development of the Michell thrust in England did away with the heavy frictional loss and wear common to the old type collar and horseshoe type. A further novel feature was to be the adaptation of an electro-pneumatic railway switch operating mechanism to a bridge control for working the main turbines directly from the bridge. In addition, the Westinghouse installation permitted a trial of the Leblanc air pump. The bridge control, although first reported successful, was later removed and conventional annunciators were installed. The gear itself was earmarked for study as to quietness and efficiency of transmission, shop tests having shown a 98 per cent efficiency and no tendency to wear when transmitting powers of 4500 H.P. for forty hours. Although this is the first large geared turbine installation to be placed on any naval vessel, Sir Charles Parsons in England had been working on the same problem and had built a set of gears for the channel cargo ship *Vespasian.* She was placed in operation in June, 1910, and was pronounced very satisfactory after a year's trial.

Concurrently with the announcement of geared turbine drive came the announcement of electric drive as a means of reducing speed from the turbine to the propeller. Broached first in the

United States in 1907, it lay in somewhat dormant state for about two years when it again revived on both sides of the Atlantic, it being suggested in England late in 1908 as particularly adaptable and useful for marine propulsion due to the possibility of securing full power for backing, a thing not practicable with the regular turbine drive. In this country Mr. W. L. R. Emmet may well be termed the pioneer in the application of electricity to main drive. His studies at the General Electric Company showed an efficiency of transmission of 94 per cent and for a battleship his early recommendation contemplated two turbo-alternators driving four main motors on two shafts. Changes in speed were to be accomplished by pole changing and with the large number of units, economies close to the maximum were promised at all speeds above ten knots.

Before adopting this latter type of drive for a major vessel, the Bureau of Steam Engineering recommended its trial in a collier, the *Jupiter* being selected for this purpose. Features especially marked for study included:

(*a*) Weight as compared with all turbine drive.

(*b*) Ventilation of generators and motors for removal of the heat generated in the armatures.

(*c*) Cooling of resistances. Under certain circumstances large quantities of heat had suddenly to be dissipated from the resistances.

(*d*) Possible failure of machines or parts of machines due to access of water.

(*e*) Complexity of accessories—switches, pole changing devices, resistances, etc.

(*f*) Degree of delicacy of speed control.

(*g*) Effect on chronometers, compasses, and personnel of grounds, the voltage being in excess of 2000.

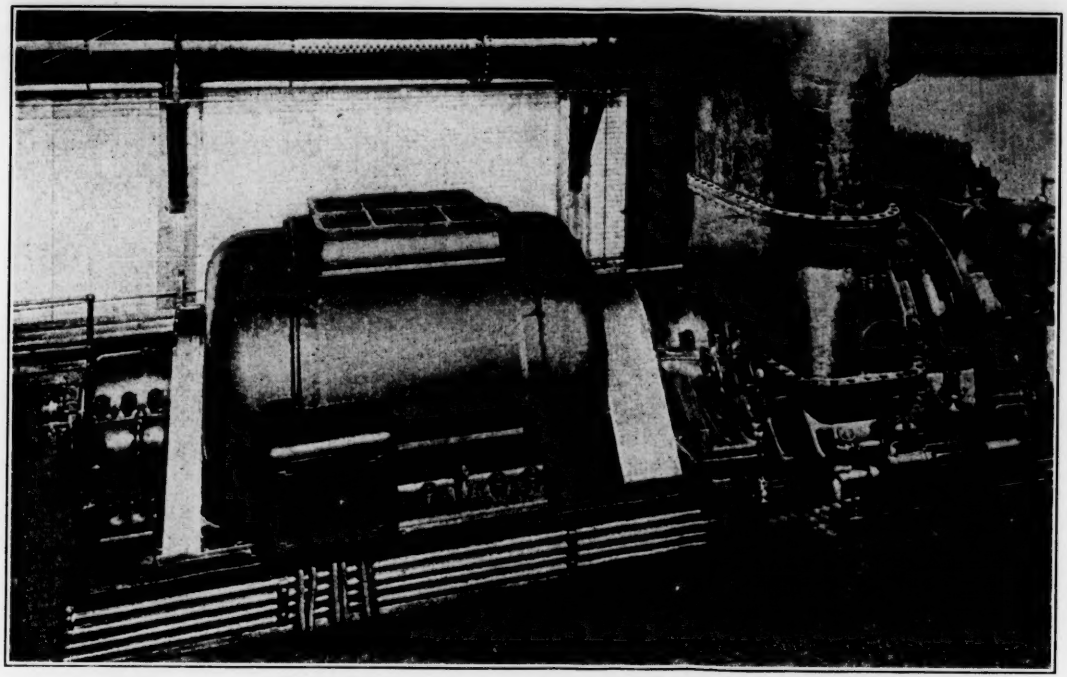
The *Jupiter,* when completed by the Navy Yard, Mare Island, was placed through an extended series of tests to determine her reliability. It is recalled that this type of drive had been suggested and recommended for the *Texas,* but due to a natural reticence in adopting such an innovation, electric drive for battleships was held in abeyance until the building of the *New Mexico* (ex-*California*). A bipolar generator connected to a six-stage Curtis turbine furnished sufficient power to drive the ship at 14 knots (Figure 11).

Two motors (Figure 12), one on each shaft, received power at 2200 volts, and as they were wound for 36 poles, an 18-to-1 reduction was obtained, the shafts revolving at 110 R.P.M. The *Cyclops,* for a speed of 14 knots, consumed 14 pounds of steam per shaft horsepower per hour, the *Neptune* following at 13.4 pounds after her propellers were changed and the *Jupiter* showing the lowest consumption at 11.1 pounds per hour. Control of speed was accomplished by frequency control, that is, by varying the speed of the A. C. generator and consequently the speed of the main motors. All features were controllable from the main switchboard, which had the added advantage of indicating instruments to show the instantaneous condition of the system.

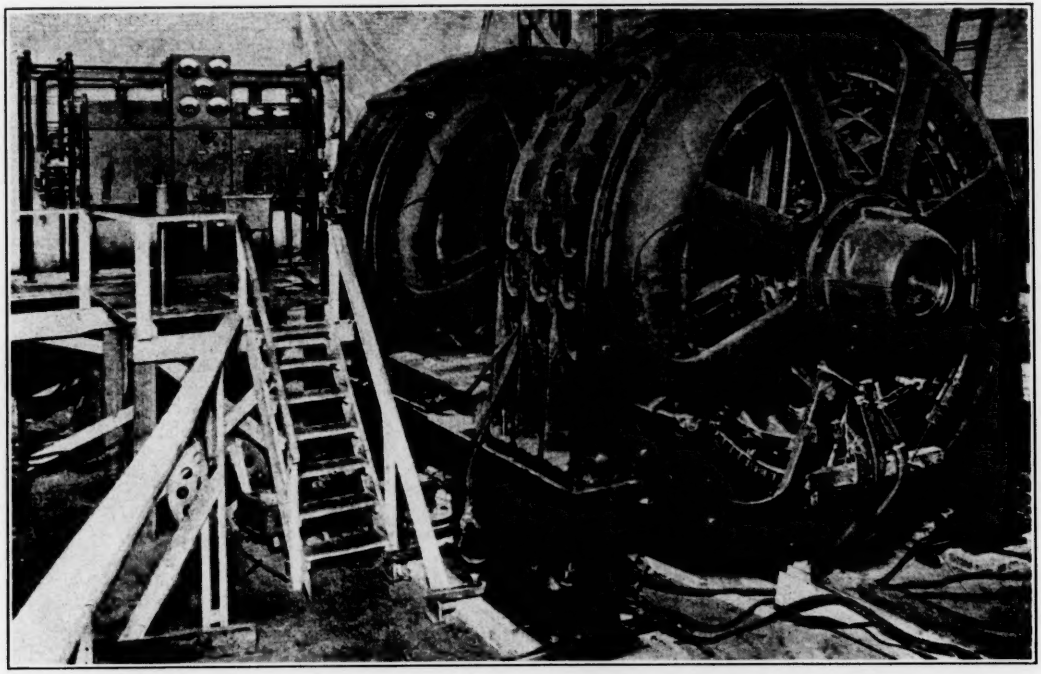
In addition to the General Electric system promoted by Mr. Emmet, the Mavor and Coulson system had also been submitted for study. The peculiar feature of this system lay in the use of a squirrel cage induction motor fitted with a spinner rotor mounted concentric with the main rotor, but revolving freely on extensions to the main shaft bearings. The inside of the spinner rotor was wound to drive the main rotor, while its outside was fitted as a squirrel cage rotor. The main stator was so connected to the external circuit that by use of two double-throw switches and a locking device for the spinner rotor, three speeds in either direction were obtainable without pole changing, without varying the frequency of the supply circuit, or without placing resistances in the rotor circuit. With the main rotor turning at 90 R.P.M. and the spinner at 60 R.P.M., three speeds at maximum efficiency of 30, 90, and 150 R.P.M. were obtainable, which for a battleship of the *Florida* class meant steerage way, 10 knots, and 20.5 knots respectively. Principal objection to this equipment was found in its weight, the overall diameter of the motors being 15 feet for an installation as proposed.

Under severe pressure from the Diesel engine interests and because some of our naval engineers were bitten by the Diesel "bug"—as stated by Admiral Dyson—the Navy Department decided to try out this form of engine, too. The fuel ship *Maumee* was selected for this purpose, plans for the two-stroke cycle engines of Nürnberg design being obtained from the Electric Boat Company (Figure 13). The New York Navy Yard performed the actual construction work and installation. After all was said and done,

FIGURE 11.



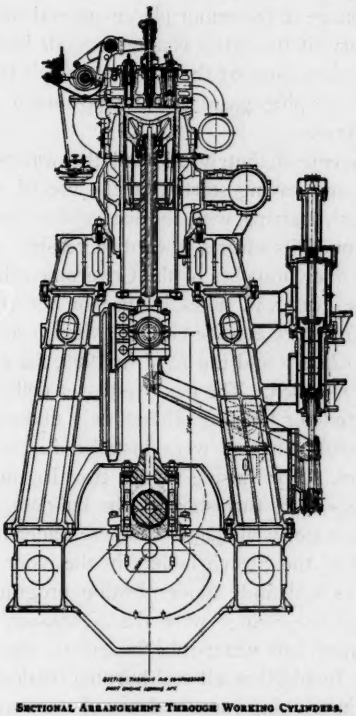
GENERATING UNIT, UNITED STATES COLLIER "JUPITER."
FIGURE 11.



TYPE 1—36-2750-110-2300 VOLT MOTORS, UNITED STATES COLLIER "JUPITER."
FIGURE 12.

the report was made that as of the year 1918 the United States possessed the highest powered Diesel engine installation afloat.

Battleships again claim attention, for the *Oklahoma* and *Nevada* now appear as new developments. The *Oklahoma* is the last reciprocating engined battleship to be built for the United States Navy, and the *Nevada* (Figure 14), the first geared turbine battleship.



SECTIONAL ARRANGEMENT THROUGH WORKING CYLINDERS.

FIGURE 13.

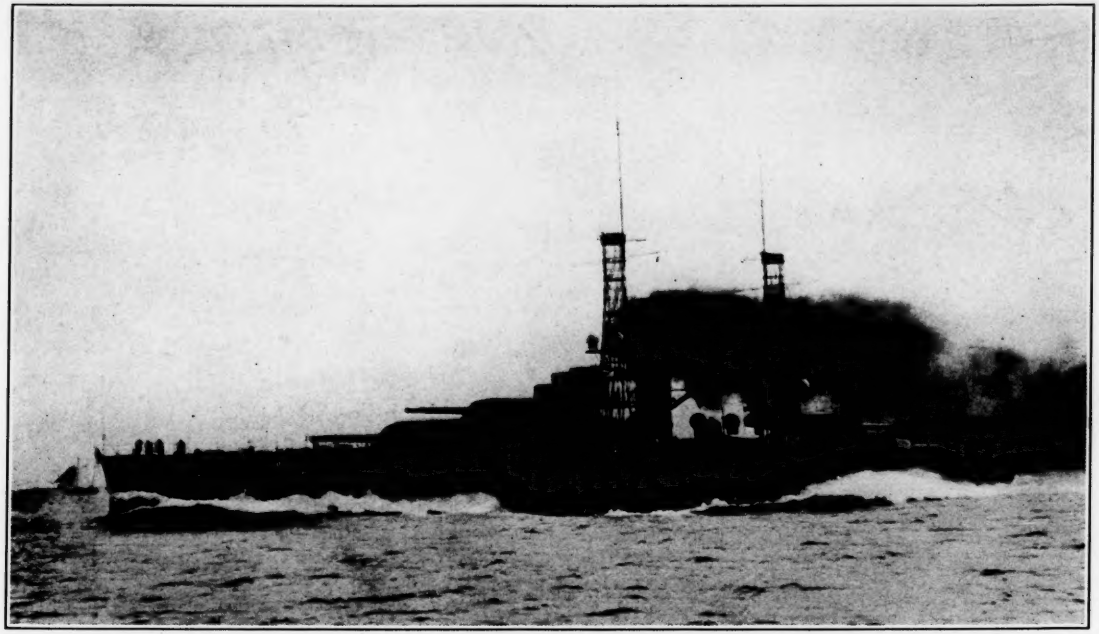
Displacement of these two vessels of 27,500 tons was larger than any previous construction. Most unusual, and probably leading most navies, was the fitting of these two vessels to burn oil exclusively, though the English in the *Queen Elizabeth* launched the first

battleship so equipped. Another feature worthy of note is the change to three-gun turrets, the lower two turrets being three-gun, 14-inch, 45-caliber, and the two upper turrets containing two guns of the same size. Even the armor placement on the two ships was altered considerably from previous types, the citadel disappearing, and two heavy protective armor decks being placed. The uptakes leading to a single smokepipe were also armored, a new departure forced by the change in the armor placement and the adoption of oil fuel. The history of this latter change extends back to the Russo-Japanese War, when some of the Russian vessels had their uptakes perforated, the escaping gases causing poisoning and consequent collapse of the crews.

The Navy, having definitely adopted the water-tube boiler for its major ships and having started on the use of oil fuel in combination with coal, starting with the battleships *North Dakota* and *Delaware,* continued its efforts toward increasing the use of these two features. Other branches of the Government began the use of oil fuel, for the JOURNAL notes its use on the hydraulic dredge *General C. B. Comstock* for the Gulf of Mexico service. With the delivery of the *Flusser* and the *Reid* in 1909, the coal burning destroyer epoch was ended. The next destroyer delivered, which was the *Roe,* was fitted for burning oil fuel only under its four boilers. Eleven Thornycroft burners were installed in the lower part of each boiler front. For raising steam two Ingram steam or air atomizing burners were furnished by the builders, as the Thornycroft burners were not well adapted for use under natural draft.

Replacements of the Scotch boilers in the older battleships was begun in 1910 as a definite modernization program. Among the ships marked for the change were the *Kearsarge, Kentucky,* and *Illinois,* which now had water-tube boilers of the Mosher design placed in them. In addition, all coal burning battleship boilers were now fitted with inswinging furnace doors of the semi-balanced type. These doors were of a type that were easy opening and out of the way. In the event of a burst tube or reversed draft, the doors would automatically close themselves. On the cruisers *Colorado* and *Pennsylvania* the old Niclausse boilers were converted into B&W boilers by replacing worn and defective parts as necessary, the old boiler furnaces and foundations being retained. Mean-

FIGURE 14.



U. S. S. "NEVADA."
FIGURE 14.

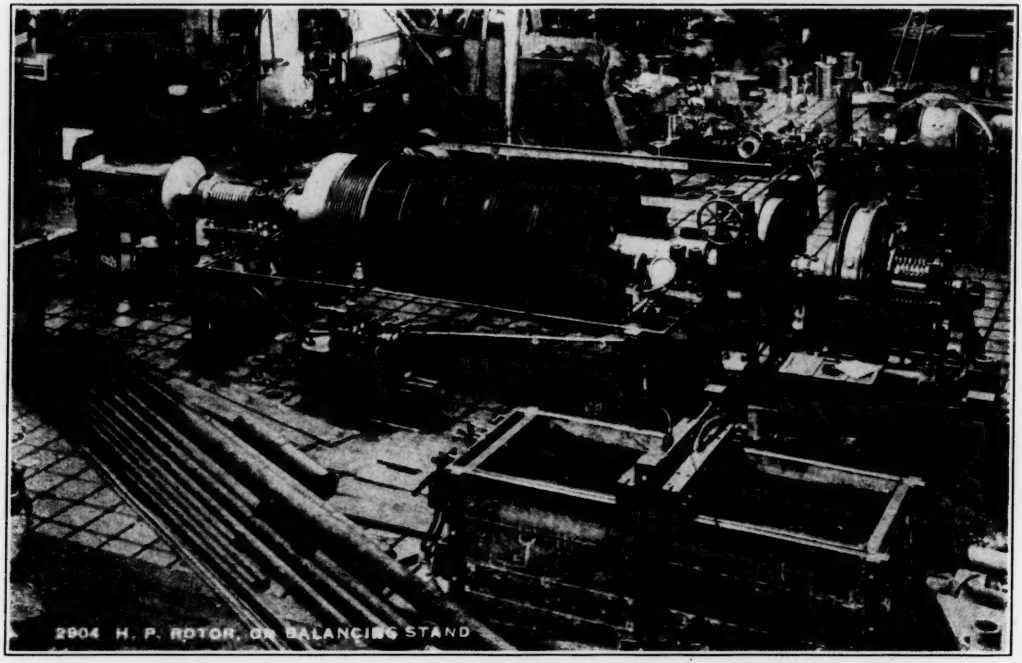


FIGURE 15.

while Yarrow introduced a "U" type superheater in the express type boiler. Shortly before this, the Foster-Wheeler Company had brought out its well-known fin tube superheater, also of a "U" shape, but fitted with radial fins.

For protection of boiler watersides a series of tests were begun and completed at the Engineering Experiment Station in 1910. To the results of the tests must be attributed the Navy's first real venture into the preparation of a suitable boiler compound for issue to the naval service. It is amusing and instructive to note the comments of a former chief engineer of the *New Jersey* when discussing feed water treatment. He noted in an issue of the JOURNAL the fact that strong soda prevented corrosion, as he heard a nurse at a surgical operation insisting upon several spoonfuls of soda in a basin of water in which she afterward dropped the doctor's instruments. The nurse stated that only in this way the instruments could be kept from corroding or tarnishing until they could be cleaned and thoroughly dried. According to the naval engineer this was his "first intimation that there was anything with water in it that was less corrosive than good neutral distilled water." The Navy standard boiler water testing outfit appeared shortly thereafter, and with this method at hand, engineers afloat were enabled to secure a considerable degree of control over their feed system and boiler corrosion problems.

Other boilers now made their appearance, for in the fall of 1912 a Newport News watertube boiler was reported on test, followed by a test on an oil burning Talbot marine launch boiler. In addition, a series of four tests were made on the old *Maryland* of Matanuska coal, an Alaskan product. Coinciding with such fuel tests were the constant efforts of engineers to improve the firing of boilers to secure the most efficient combustion. The Experiment Station furthered these efforts by introducing the Orsat gas analysis apparatus by which a quantitative measurement of flue gas composition could be made. In some of the later destroyers experimental smoke indicating systems were fitted by which fireroom personnel could visually determine the condition of the stack gases.

Further tests continued, the entire boiler situation and fuel oil burning methods being in a constant state of flux. The *New York*, although fitted primarily for coal burning, had her boilers designed

with larger furnace volumes to burn oil more efficiently. A new design of Ward boiler, similar in appearance to the B&W, was given a series of tests at the Naval Fuel Oil Testing Station in 1915, while on board the submarine tender *Fulton* experiments were made on oil burning with natural draft. The fuel oil burning situation was much cleared by the development of new lubricating and fuel oil specifications published in 1915, and by the invention of improved types of film oil heaters, the Lovekin and Schuette-Koerting being two of those offered at that time.

Referring again to the battleships *Oklahoma* and *Nevada,* which marked the return of the raised forecastle which had been abandoned temporarily for the flush main decks of the preceding four ships, we find a difference from former vessels in compartmentation for the stowage of fuel oil. The *New York* was the first battleship to be fitted with Pneumercators for registering the contents of the oil tanks. Oddly enough, the description of the *Oklahoma* shows a return to the Allen dense air ice machine, abandoning the carbon-dioxide type fitted on her predecessors. Resulting from the design of the newest battleships as oil burners, a 300-ton reduction in fireroom weights was made on the *Nevada,* and the fuel for the necessary cruising radius was decreased in the proportion of nine to seven. Most remarkable was the reduction of the fireroom force by fifty per cent and a reduction of boiler room space from 128 feet in overall length to 66 feet.

An examination of the *Nevada's* engineering plant layout does not indicate that a radical change in turbine propulsion has been made, for with the return to turbines, the high and low pressure turbines were tandem connected to the same shaft. Each turbine was in a separate compartment with a small alcove in the forward engine room set aside to receive a small double reduction geared cruising turbine capable of being disconnected at high powers by means of a jaw clutch. The gear itself was of an English design known as the Alquist. The opening of the bids in 1913 for battleship number 38, later named the *Pennsylvania,* introduced to the Navy its first large all geared turbine installation, where the Curtis turbines were entirely coupled to the shaft through the medium of single reduction gears. The *Pennsylvania* and her sister ship, the *Arizona,* marked the arrival of the twelve, 14-inch gun ship, displac-

ing 31,400 gross tons. In the next year, a proposal to build 38,600-ton battleships was submitted to Congress, but was rejected. Data on foreign ships, particularly British and German, for various reasons was now becoming more scarce, though a note appeared at this time that the British in the *Queen Elizabeth* had a ship of 27,500 tons and 25 knots speed, and the French had plans for a 32,000-ton ship. Gun calibers in foreign navies remained at 13.5 to 14-inch. It was remarked that the *Dante Aligheri* of the Italian Navy was their first to have 3-gun turrets, though the idea was abandoned in 1913. The French proposed a 4-gun turret, but nothing came of this. Battle cruisers appeared in practically all navies but our own, though these were constantly urged upon Congress by the Navy Department. It is worthy of note that the British battle cruiser *Princess Royal* made 32 knots on her trials in 1912, and after changing propellers, made a peak speed of 34.7 knots.

Following *Pennsylvania* and *Arizona*, a slight lull occurred here in the face of the agitated conditions in Europe. The United States Fleet was up to this time rated as second in strength to the British, having replaced the German Navy in that position. In June, 1914, Congress authorized the construction of three battleships, the *New Mexico, Idaho,* and *Mississippi,* but these vessels were not delivered until 1918, and later, when the World War interfered with their building. In the hulls of these vessels a considerable change is found, the first being the adoption of a clipper bow and the second being a large increase in compartmentation as a protection against underwater attack. Several other valuable features were also adopted, particularly those relating to fire and ship control. The *New York* was equipped for the alternate use of steam or electricity on its opposed screw type steering gear, while later ships were fitted for electric steering only. Alternating current began to find some use in certain intercommunication systems and the gyro compass made its first appearance around 1912. Two Argentine battleships, the *Rivadavia* and *Moreno,* built at the Fore River Shipbuilding Company, furnished an indication of future interior control to come when Selsyn systems were installed in them. This is the first naval use noted for a system of this type, although it had previously been incorporated in the lock controls for the Panama Canal.

Subsequent to the *Henley*, a small group of destroyers was built with reciprocating cruising engines on one shaft for use up to 16 knots, the *Cassin* and *Cummings* being of this type. The jaw type of clutch which had formerly been used was unsatisfactory in coupling up the engines, and was now replaced by rigid coupling. Even with these improvements, destroyer propulsion was unsatisfactory until the trials of destroyer number 60 in 1915, the *Wadsworth* (Figure 10), which was fitted with Parsons turbines and reduction gearing of a single helix type instead of the herringbone gear. A small group of destroyers between the *Wadsworth* and the *Cassin* had been fitted with cruising reduction gears disconnected by a hydraulic clutch. The *Tucker* (Figure 8) may be cited as an example of this particular group.

The panorama of changes which has been pictured in the preceding paragraphs marks the final major change to ships for our Navy. From this point on few new designs occur and those which do appear are adaptations of older ones. To the engineer who operated the huge powers placed in his hands, stability and economical performance were now by-words. In consequence of the competition forced upon ships of similar classes resulting from the World Cruise of 1907-1908, the *Michigan, Flusser,* and *Reid* made a series of trial runs in water of various depths in 1910. Such runs had been made previously, but no accurate data had been taken. Runs were made in both deep and shallow water after the ships had their bottoms cleaned, and as had been long suspected, less power was required to make the required speed at higher powers in deep water than in shallow water.

The beginning of the "Round the World" cruise was recorded in a previous installment. That cruise has left its mark on the career of the engineer of today in the form of an engineering competition. It all began when the Commander-in-Chief inaugurated a steaming competition on the first lap of the cruise, which was the passage to the West Coast of the United States. As a result, 1460 tons of coal were saved on the battleships as they steamed between Rio de Janeiro and Magdalena Bay. Later, 2000 tons were saved in the passage from Honolulu to Auckland. The competition was held between vessels of the same class to give comparable results.

Each ship kept a record of its speed, efficiency and economy, the amount of coal burned, the hours under forced and natural draft, and the distance covered. It is recorded that Lieutenant Commander Gillis first suggested such a competition in a letter to the Navy Department in August, 1906. After the return of the fleet, the first official competition was instituted and has been continued to this day. Cash prizes were offered the winning ship's personnel, chief petty officers receiving 15 dollars, and coal passers 5 dollars, to mention two examples.

The following year, 1909, marked the establishment of the School of Marine Engineering at Annapolis, the school being created in a General Order issued by the Secretary of the Navy. Postgraduate instruction was now afforded the many line officers who desired to further round out their engineering experience. Originally using the facilities of Isherwood Hall at the Naval Academy and those of the Engineering Experiment Station, the school finally secured its own quarters in the old marine barracks on the Academy grounds. In 1912 the name of the school was changed to Postgraduate Department, U. S. Naval Academy, a name held to this day. Student officers, in addition to assisting at various tests at the Experiment Station, made several original tests of their own, such as the 1916 turbine blade erosion tests.

Coupled with the activities of the Postgraduate School, but entirely independent of it, was the Naval Engineering Experiment Station mentioned in the previous installment. A large number of tests were made covering almost the entire field of engineering endeavor. Of course, the Bureau of Engineering was not alone in experimentation, for the other bureaus were proceeding along similar lines. As an example, the studies at the Norfolk Navy Yard by the Bureau of Construction and Repair resulted in a cheaper paint for the Navy, the first ready mixed paints being issued in 1911 after paint formulas had been developed in 1909. Again, the advent of oil fuel forced a study of oil fires; a board was appointed for this purpose in 1910, and as a result of its findings, the foam fire extinguisher patented by the Standard Oil Company in 1911 was recommended for adoption, and fitted to all oil-burning vessels.

Not long after the Experiment Station was established, a set of micro-analytical equipment was installed for a more accurate study of metals, particularly where failure had occurred. Such studies had become of importance following several shafting failures in older ships. A thorough investigation of these failures and engine vibration was undertaken in 1916 on vessels of the *Louisiana* class, such as the *Minnesota* and *Kansas,* and careful examination disclosed the fact that propellers were not responsible for the failures. A special torsion meter was built for this work and revealed the cause as being critical speeds of synchronous torsional vibration. Some attention had previously been directed to a vibration study on these ships as the engines were quite noisy at speeds of 80 to 81 R.P.M. No previous mention of this type of failure had appeared in the JOURNAL, however, and the appearance of the article at this time launched a new study in mechanical dynamics for the Navy.

Further study in basic design and construction was forced on shipbuilders and contractors by the demand for turbines of higher speed in connection with reduction gears. During the direct drive turbine installation era, very little attention was paid to dynamic balance of the rotors because of the low speeds. With geared turbines, governors had returned because of racing in a seaway and the high rotative velocities incurred. In 1915, Parsons had introduced thin tipping of blades and shrouding to protect against radical changes in clearance, and he also incorporated an impulse element with the reaction blading. A year later Akimoff presented an article on dynamic balancing which outlined mathematically the reasons for dynamic unbalance and its correction. Not until 1918-1919, though, did the Experiment Station test any types of balancing machines. The Mare Island Navy Yard also did some missionary work in balancing the *Shaw's* rotors. In those years, the General Specifications for Machinery, United States Navy, called for a static balance on knife edges, then dynamically under steam in the casing at 25 per cent excess speed. This was done at Mare Island, but only after the rotor had first been tested on a balancing machine produced locally (Figure 15). The results were excellent, but when the article describing the method was published, somewhat of a friendly controversy was raised between the author of the article and Mr. Akimoff. As the JOURNAL has always been published for

the purpose of disseminating technical knowledge of interest to the engineering profession, this controversy was one of special interest.

Other tests of importance that may be mentioned here are the packing tests in 1914, and the development of the work-factor test which thereafter became a standard for the purchase of many consumable articles used by the Navy. Lubricants were placed under test and standard series of lubricants were listed for the first time. Boiler gaskets and packing came in for joint examination at both the Experiment Station and the Fuel Oil Testing Plant at Philadelphia, while the latter made an extended research on refractories beginning in 1919. For material examination, an impact testing machine was developed at the Experiment Station, and in a series of major performance tests, a Reilly submerged coil evaporator was placed on test in 1916 for a period of ten months. In 1915, the largest experimental wind tunnel in the world was built at the Washington Navy Yard.

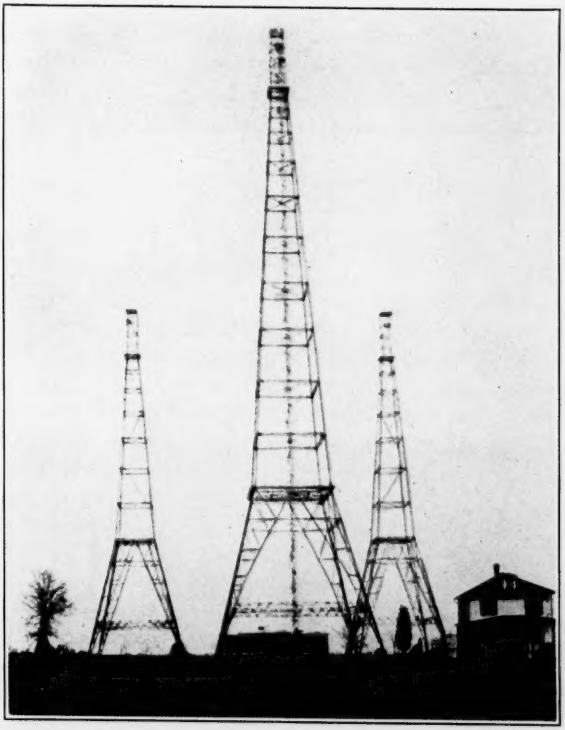
While the major portion of the experimental work of the Navy may be termed scientific, it is of a somewhat quasi-scientific nature with the practical phase continually accented. Radio and sound studies are carried forward primarily to produce sound equipment, and effective radio stations. The period from 1899 to 1908 introduced radio or wireless telegraphic facilities to the attention of the various governments and commercial interests. Its use was accelerated by the loss of the steamship *Republic* in 1909, when radio played its first major role in the rescue of lives at sea. A related study was also begun with the launching of the magnetic survey ship *Carnegie,* which cruised the oceans for many years studying, recording, and observing magnetic disturbances over the earth.

A large number of private radio stations were appearing along the Eastern seaboard of the United States along with an increase in the number of naval stations. However, due to the increase in effective range of the various transmitters, the original number of stations contemplated was cut down considerably. Government ownership of all radio stations was discussed, but was never legislated. A most important suggestion was made in 1908, when the U. S. Naval Radio Telegraphic Laboratory was recommended. In its founding, the Bureau of Standards cooperated whole-heartedly and research was begun into the measurements and determinations

of natural radio laws. Even at this early date the probability of reflection of waves from conducting layers of the upper atmosphere (Kennelly-Heaviside) was mentioned.

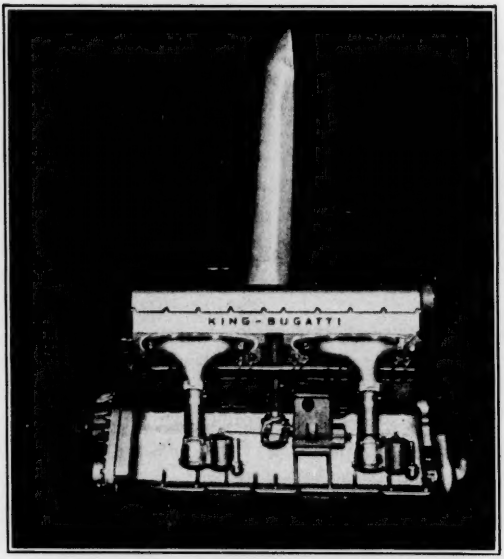
The opening of the 1912 International Radio Conference in June of that year established another milestone. In attendance were a varied group of officials, 41 per cent being post office and telegraph officials, administrators, and engineers. Fully one-third were military and naval officials, as Europeans recognized in this means of communication its great importance as an instrument of war. Rear Admiral J. A. Edwards, U. S. N., of the Bureau of Steam Engineering, served as chairman of the United States delegation, each member for diplomatic reasons being commissioned as a "plenipotentiary." The United States took an early lead in making the conference successful. Among recommendations put forth by the United States were the use of 600 meters (500 kilocycles) as a standard calling wave length and distress frequency, and the use of "sharp tuning" for transmitters to reduce interference. A United States law was passed which prevented a vessel carrying 500 or more persons on board from going to sea without radio equipment. The "safety at sea" feature was given greater attention than usual that year as a result of the loss of the *Titanic*. Upon the close of the conference another was proposed for 1917, but due to the World War, this was not held.

In the United States the development of the art proceeded apace. The large naval station at Arlington was placed in commission in 1912 (Figure 16) and at that time was the most powerful in the United States. To the "old timers," the mention of a Fessenden rotary spark equipment may bring smiles and reminiscences, but to the designers of that time it was practically the latest and best available and was therefore used. The range of the station was such as to reach the fleet at any point of the coast of the United States and in its construction it marked the beginning of the present day Naval Radio network. Shortly before, an expedition had left for Alaska, the purpose being a comprehensive radio survey of that territory for the establishment of the coastal network. Quantitative experiments on radio transmission energies had been started in 1909 and 1910 utilizing Brant Rock, a naval radio shore station with Fessenden equipment, and the *Birmingham* and *Salem*, afloat.

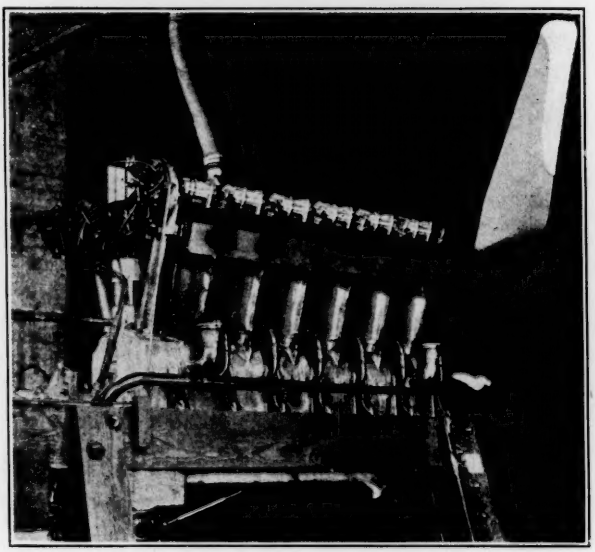


NAVAL RADIO STATION, ARLINGTON, VA.
(LOOKING EAST.)

FIGURE 16.



KING-BUGATTI AIRPLANE ENGINE, 16 CYLINDERS.



LIBERTY MOTOR, 12 CYLINDER, 400 H.P., STANDARD.
U. S. AERONAUTICAL ENGINE.
FIGURE 17.

When Arlington became a reality, the experiments were repeated, but for longer distances with the station's arc and spark apparatus, the night signals being so strong that they were heard at Gibraltar. Later, after an intensive study of the radio phenomena had been made; the problems were more clearly understood; and the personnel understood the equipment better; much greater ranges were obtained at lower transmitting powers.

Undamped or continuous waves were found to be the best media of transmission, yet they were troublesome in reception, as special equipment was necessary. At Arlington, an arc transmitter served to generate continuous waves; while at Tuckerton, New Jersey, a new development, the Goldschmidt alternator, specially built to generate waves at radio frequencies, was installed. Vacuum tubes had been devised about eight years before, but their use for transmitting purposes was then in the making.

The year 1914 marks the first mention of the radio compass with its loop antenna. Directional effects of various types of antennae had been observed in the past and it was to overcome such effects that the triangular flat top aerial had been used at Arlington. However, by using the rotatable loop with a good receiver a means was now provided for securing with reasonable accuracy bearings of any radio transmitter. Installation of radio compass stations at various strategic points along the coast of the United States followed and with this accomplishment the military forces of the country placed another milestone in the constructive development of civilization.

Two years after, the art of radio had reached the stage where radio telephony was carried on between Arlington, near Washington, D. C., and the Eiffel Tower in Paris. The experiment was opened with great ceremony and attended by many notables from both countries participating. A very pronounced impetus was given to the use of radio telephone equipment by the World War. Aircraft in particular used such equipment and the Army Signal Corps developed a wind driven generator to be used with a vacuum tube transmitter.

A few more facts may be added to this short description of radio development. When the United States became a participant in the overseas war, it became necessary to insure communication security and the construction of a large station of 1000 kilowatts at

Croix d' Hins, at Bordeaux, and of a similar station at Annapolis, Md., was begun. The French station was not completed until after the War, but its entire installation was undertaken and completed by the United States Navy, the first communication being started on August 21, 1920. One other important result of the War was the formation of the Radio Corporation of America. When, at the war's close, it appeared that the commercial radio stations in the United States would pass into foreign hands, the insistence of the Navy Department brought about the formation of the largest radio company in the world, the company being formed by the General Electric Company, Westinghouse Electric and Manufacturing Company, and the Wireless Specialty Apparatus Company.

A newcomer which now appeared in military circles was the airplane. Starting from a small beginning, its first mention appeared in the 1909 issue of the JOURNAL, when a British Army airplane was described. The airplane received its first attention from the United States Navy at about this same time. Nevertheless, very little mention is made of this science in early issues of the JOURNAL. We note only that early in its career, flights from the decks of warships were tried, the earliest such being a takeoff from a platform built on the guns of the *Birmingham*. Development must have been quite rapid even though little appeared, for in 1914 a Curtis 200 horsepower "V" type engine was tested preparatory to a trans-Atlantic flight, and Sperry had developed his airplane gyro stabilizer.

In these early days there was no Bureau of Aeronautics in the Navy Department as there is now, that Bureau first coming into existence in 1921. Power plants of aircraft were under control of the Bureau of Steam Engineering and structural parts under the Bureau of Construction and Repair much as present day surface ships are divided in cognizance. European countries were much in advance of this country in the development of military aircraft, and several European abstracts appeared which gave the functions of aircraft in war.

Airplane power plants gave much concern. The principal and probably only reliable source of power was the gasoline engine which necessarily had to be reduced in weight and increased in power to fit it for flight duty. In this feature particularly, European

nations led, one of the most famous foreign engines used in our service being the King-Bugatti, built here by Duesenberg (Figure 17). However, this superiority did not last long, for as the European nations became engaged in warfare American airplanes and motors equal to Europe's best were building in 1917 (Figure 17), the industry and technical achievements having advanced tremendously since 1915, culminating in the famous flight of the NC4 across the Atlantic in 1919, an episode of no small proportions.

As with foreign aviation developments, foreign naval shipbuilding showed rapid advance and in many cases paralleled developments in the United States during this period. Turning back for a few years, the British destroyer *Velox* and steamship *Otaki* are cited as the first to be equipped with reciprocating engines at about the same time our American destroyers were being so fitted. In the *Otaki,* built for the New Zealand Steamship Company, a different arrangement than usual was used, reciprocating engines on each of the wing shafts exhausting into the low pressure turbine on the center shaft. The reciprocating engine turbine combination held the fore for several years, one of the largest passenger liners launched in 1910, the *Olympic* of the White Star Line, having such a propulsion unit. Experimentation with producer gas engines was tried for eight months on the British *Rattler.* An entire anthracite producer gas generator was carried on board to furnish gas for a pair of producer gas engines that had been fitted for main propulsion. This installation, novel as it was, probably came in the same class as our *Maumee,* which started building two years later. Lloyd's in 1911, listed twelve merchant ships fitting with oil engines and in that same year the Germans were noted as building 6000 horsepower, 2 cycle double-acting Diesels of 150 R.P.M. for one of their war vessels. Yet the first seagoing vessel with reversible Diesels is credited to the Dutch *Vulcanus,* which could be reversed in 12 seconds. A very complete article on the Diesel engine was published in an article by Dr. Diesel in the 1912 JOURNAL. This engine, which offered great fuel economies, was rapidly adopted in Europe. It also furnished an excellent solution for the dangerous conditions resulting from the use of gasoline engines in submarines, and was early adopted for that class of craft. The first seagoing Diesel engined vessel is quoted as the *Selandia,* which had two Ger-

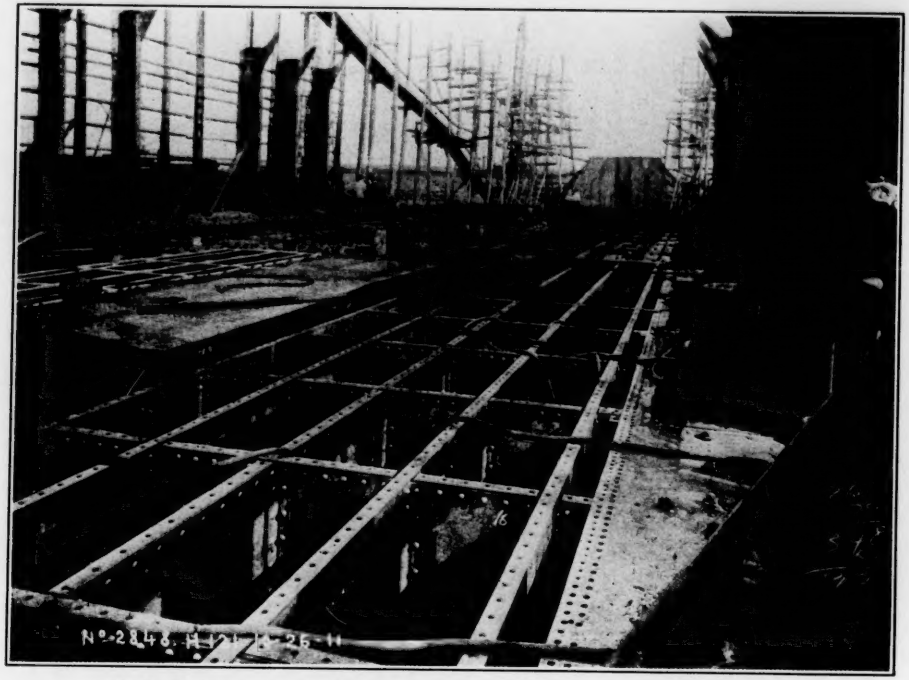
man-built engines of 1250 brake horsepower each. To the Hamburg-Amerika Line belongs the credit for the first Diesel vessel to visit New York, the *Christian X.*

Other changes came from abroad, one of the most important being put forward as a competitor for the mechanical reduction gear. Such was the Föttinger, or Vulcan hydraulic clutch, invented in Germany in 1909. Its use as a reduction gear was never considerable, though as a coupling medium it has found great success. Germany, at the same time fitted one of its destroyers, the *G-173,* with Zoelly turbines as a trial. Although Curtis impulse compounded turbines were a distinctly American development, the British found occasion to place them in the cruisers *Bristol* and *Yarmouth,* and in the *Neptune* the British eliminated cruising turbines, lengthening the high pressure turbines to correspond. Italy also began using turbine drive by placing them in the cruiser *San Marco.*

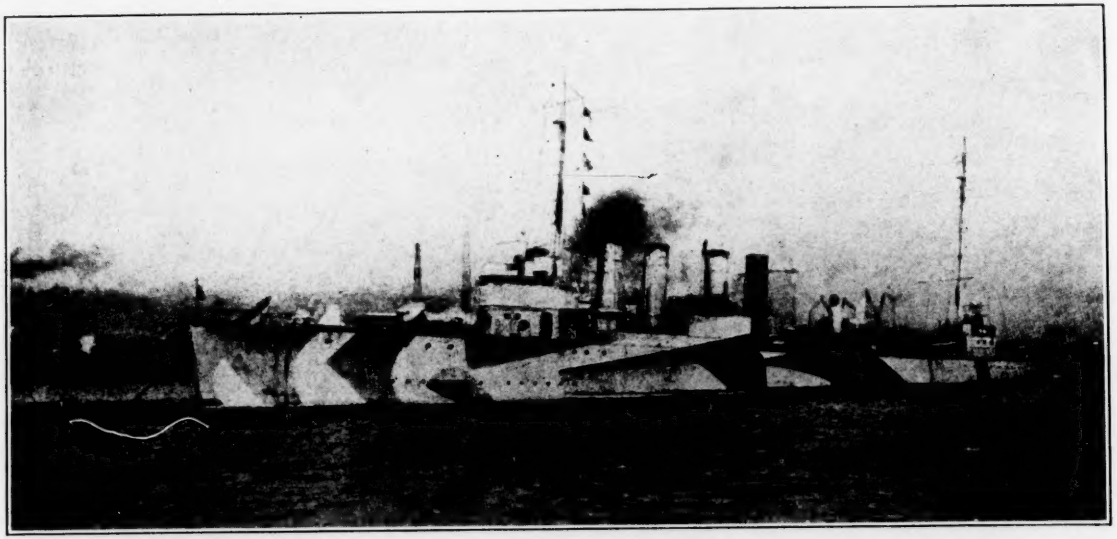
Size had also its part to play in the new designs being created. At the launch of the *Lion* in August, 1910, the largest battle cruiser in the British Navy took the water. She was 700 feet long by 88½ feet beam, displacing 26,000 tons, and made 30 knots on an indicated horsepower of 70,000. Her high and low turrets had their first British predecessor in the battleship *Orion.* Brazil in turn astonished the world with an order on Sir W. H. Armstrong Whitwork for a 32,000-ton battleship to be equipped with twelve 14-inch guns and completed in two years.

Although battle cruisers had been strongly recommended for the United States Navy in 1912, the point being made that many were building in foreign countries, a deaf ear was offered to the suggestion by Congress. The British *Lion* mentioned before belongs to this class, the German *Moltke* also, and the British-built Japanese *Kongo* of 28 knots speed is also included in the type. The latter, laid down in 1911, with three similar ones building in Japan, was at the time of her building known as the most powerful armored vessel afloat. Her dimensions of 704 feet length by 92 feet beam were larger than any of her foreign competitors. In addition to 4000 tons of coal, 1000 tons of oil were carried. Her armament was quite heavy, consisting of eight 14-inch guns, sixteen 6-inch broadside guns, and six 21-inch torpedo tubes. Yet the British *Tiger,* laid down in 1912, with 99,000 horsepower, quickly replaced

U. S. S. "Orion." Isherwood System of Framing in Double Bottoms.
Figure 18.



U. S. S. "Orion." Isherwood System of Framing in Double Bottoms.
Figure 18.



U. S. S. "DENT"; DISPLACEMENT, 1159 TONS; SHAFT HORSEPOWER, 28,190; SPEED, 36.88 KNOTS.
FIGURE 19.

the *Kongo* just one year later. Other large vessels for other nations were building, the *Almirante Latorre* and *Cochrane* for Chile being cited.

While engines and boilers were showing improvements and advances, hull design progressed with the times. The Germans had become a race of shipbuilders and many of their outstanding developments have been cited. In hull stability they now brought out (1911) anti-rolling tanks, an old idea, but perfected to its final state in Germany. At the same time the English, a distinctly maritime nation, through Sir Joseph Isherwood, produced a vessel with longitudinal framing for certain strength members in place of the old established transverse framing. The collier *Orion* (Figure 18) was the first American naval vessel to use the system, while the British *Ardent,* delivered in 1914, marks its first use in one of their destroyers.

Many other new ships may be listed, but space does not permit. An electric drive motorship, the *Tynemount,* was built in England for service on the Great Lakes and Canals of North America. The Swedish builders placed a Ljüngstrom turbo-electric drive in the *Mjölner* in 1916. By far, one of the greatest changes from the old to the new was the adoption of the Kingsbury thrust bearing in the United States and of the Michell thrust in England almost simultaneously. The passing of the old horseshoe and collar type thrust was rapid, as the newcomer solved the question of critical clearances, and substituted a thin wedge-shaped film of oil upon which to take the propeller thrust.

Efforts on the part of several nations to postpone a major conflict came to naught in August, 1914, when Austria declared war on Serbia. One nation after another quickly entered the conflict and a world war was underway to last for four years. Almost twenty years after at this writing its effects are still pronounced in every walk of life. One of the causes of the war, undoubtedly, was the political aspect of the international armament race. Criticism was leveled against the British in one statement which was made to the effect that the *Dreadnought,* because of the unprecedented secrecy attending its design and construction, became the best advertised ship in the world and ushered in an era of world-wide competition in battleship building. A review of JOURNALS during

the early war period reveals the absence of any mention of the war until February, 1915, when the quick mobilization of the British Fleet at the outbreak was remarked upon. Information now became very scarce and for several years a dearth of foreign shipbuilding notes is conspicuous.

Of course, large shipbuilding programs by this time had taken the attention of most nations, and ships of all types were placed under order. To the Allies, with whom we joined in 1917, the maintenance of a service of supply was the most grievous problem. Submarines were taking a heavy toll of shipping, in fact, at a rate greater than ships could be built. Consequently, two very important objectives arose. The first thought was to protect the ships of the train from torpedo attack and to effect this the convoy system was adopted whereby a group of supply ships and transports were escorted in special type of formation by a screen of destroyers or other high speed vessels from one port to another. The second objective was accomplished through the creation of several new weapons and methods, such as the 300-pound depth bombs fired or dropped from destroyers and other craft; the North Sea Mine Barrage, which tended to confine the submarine's operations; the perfection of submarine listening devices; the building up of a large fleet of "mosquito boats" and destroyers equipped with special devices for combating submerged submarines; and lastly, the building of submarines as counter-weapons.

The United States, just prior to its entry into the War, foresaw the inevitability of being drawn into the maelstrom, and launched a gigantic building program consisting of four 32,500-ton electric drive battleships, incorporating lessons learned from Jutland with respect to armor plating, underwater protection, and interior arrangement. Fortunately, in the three years preceding, several different auxiliaries had been built from necessity, and experience had been gained in their operation. Among these were the first submarine tender, *Fulton,* built to merchant ship specifications and fitted with a single 1000 horsepower, two-cycle single-acting Diesel engine which drove the ship at a mean high speed of 12.785 knots on her trials in October, 1914. Two small boilers, one an Almy, the other a Roberts, furnished steam for various purposes. The main engine also served to drive the storage battery charging generators,

while a turbo-generator set furnished the ship's light and power. Following the *Fulton* came another submarine tender, the *Bushnell,* with a geared turbine drive and a cableship bow for lifting submarines, and the destroyer tender, *Melville.*

The most famous of our auxiliaries remained the *Jupiter,* which, because of its electric drive machinery, was constantly under critical surveillance, and was used for many comparative tests with vessels of other types of steam motive power. One collier, the *Vestal,* was removed from service and rebuilt into a repair ship in 1914. Another conversion was made by taking the cruiser *Dixie* and refitting her as a destroyer tender. She is notable in that she was equipped with Lillie four-stage evaporators, and had the first electric bake oven in our Navy with a capacity of 800 loaves per day. Among other floating craft may be listed the first American revolving floating crane of 150 tons capacity built for the Navy Yard, Norfolk, by the Wellman-Seaver-Morgan Company.

Submarines received some degree of attention, though from the record a reticence seems to have attached to building large numbers of these craft. Whether it was an ulterior motive or several tragic foreign losses that prompted this attitude is not disclosed by the record available. However, the Navy in building its "F" boats now changed over to the Diesel engine for main surface propulsion. Experiments were also undertaken to use the Edison storage battery instead of the lead-acid battery, but after a disastrous explosion in one of the "E" boats, the lead-acid battery became standard equipment. One of the earliest long distance cruises by a submarine was that of the *Salmon,* built by the Electric Boat Company, from Quincy, Massachusetts, to Hamilton, Bermuda. The wariness of the underwriters in accepting this risk is noted in the requirement that a convoy accompany the craft on the entire trip. Most of the changes that had taken place on the undersea craft were in the nature of control and better superstructure, but in 1915, despite our country's excellent record, the *F-4* foundered off Honolulu with the loss of her entire crew. From this time on and for the succeeding five years several new classes of submarines were building, each of increasing size, and grouped into a second and first line type. Early submarines of the H type were completed in 1913 and 1914 followed by several more in 1917 and 1918. The K, O, R, and S

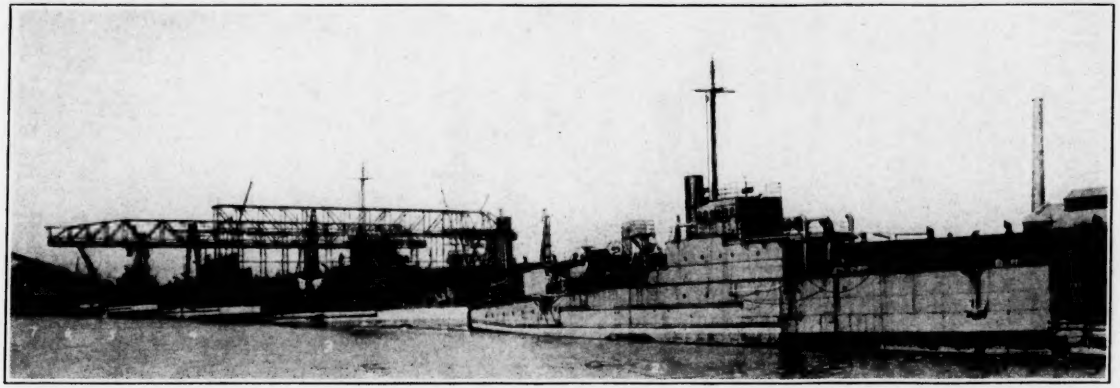
boats followed in rapid succession, practically all except the R and S boats seeing service during the war period.

By far the largest amount of construction was performed in the building of smaller vessels from destroyers downward. The following table lists the horsepower constructed during the two years of the United States' participation in the war, a total of 9,501,440 horsepower:

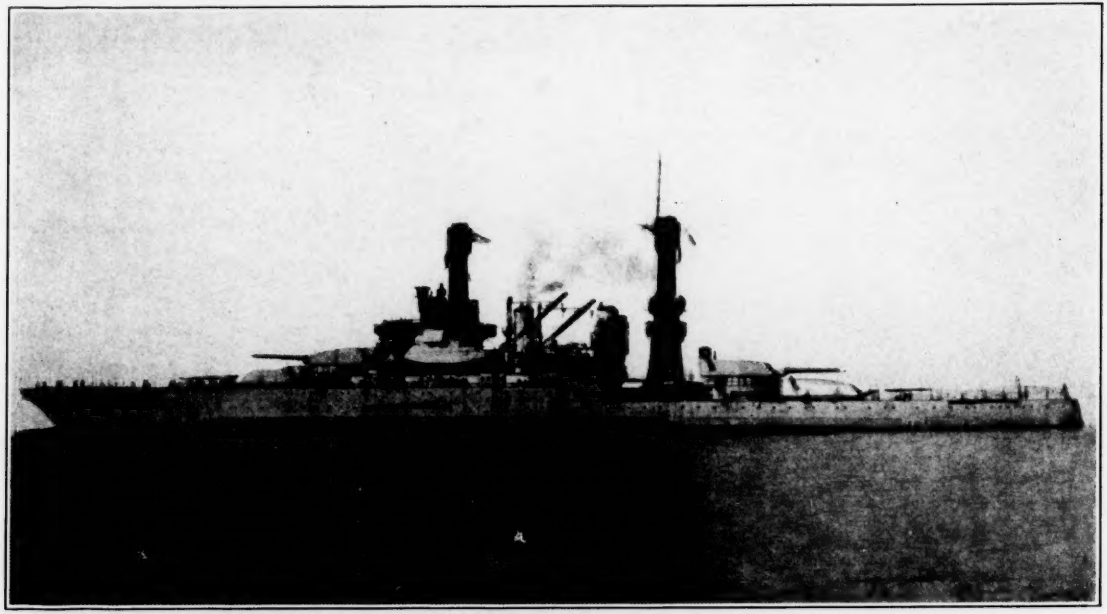
Destroyers	6,578,000
Battle Cruisers (6 ships)	1,080,000
Battleships	480,000
Scout Cruisers	630,000
200-Foot Patrol Boats	280,000
Mine Sweepers	75,600
Seagoing Tugs	48,600
Submarines	41,640
Emergency Fleet Corp. Oil Tankers	31,800
Harbor Tugs	12,000
Fuel Ships	10,400

The destroyers ranging from destroyer number 75 to destroyer number 347, with the exception of eighteen which were subsequently cancelled or their contracts not let, were built under authorizations of Congress passed between August, 1916, and July, 1918. All were of the same general type (Figure 19) with an overall length of 314 feet 4½ inches, extreme breadth of 30 feet 11¼ inches and a draft of nine feet or more corresponding to displacements of 1154 to 1215 tons. Characterized principally by their flush decks and four smokepipes, they have remained in active service for many years. Earlier boats of the program were fitted with wooden masts and foundations for four 4-inch, 50-caliber guns. As war experience was gained, the mainmast was replaced by a small stubmast, foundations for five 5-inch, 51-caliber guns were fitted, and the 24-inch searchlights moved abaft the smokepipes. Depth charge racks, a 3-inch, 23-caliber antiaircraft gun on the stern, and four triple 21-inch torpedo tubes completed the armament.

Machinery varied according to the shipbuilder, but all had the same general arrangement with turbines and reduction gears alter-



THE "EAGLES"—FORD BOATS.
FIGURE 20.



U. S. S. "TENNESSEE."
FIGURE 21.

nately disposed in two engine rooms. Five different types of main propulsive units were evident.

Parsons geared turbine.
Fore River Curtis geared turbine.
General Electric Curtis geared turbine.
Westinghouse geared turbine.
Newport News Curtis direct drive turbine with one geared cruising turbine.

Originally designed for a total of 24,200 shaft horsepower per ship, the requirement was raised to 27,000 in later ships. Single reduction gears with a high and low pressure turbine on each coupled the turbines to each of two screws except in the General Electric ships, where two idler gears were interposed between the pinion and bull gear. As usual, the Westinghouse gears were fitted with floating frames, while the others were of the rigid type. All carried Kingsbury thrust bearings, either in the gear housing or at the forward end of the main turbine, except in the General Electric installations, which had their own type of thrust. Several of these destroyers exceeded 35 knots on trials and one, the *Ward,* was built at Mare Island in 70 days from keel laying to commissioning, and at Squantum one was built in 45½ days. (See Figures 7 to 10, which illustrate older types also.)

Four water-tube express type boilers, two in each fireroom forward of the machinery spaces, furnished steam for all equipment. Each boiler had its independent uptake and smokepipe. The firerooms were operated on the closed principle with three blowers to each. All boilers burned oil and generated steam at pressures ranging from 250 to 265 pounds per square inch.

The 200-foot patrol boats or "Eagles" were of simple lines capable of being rapidly fabricated (Figure 20). Their displacement of 500 tons with a singe screw 2500 horsepower turbine drive gave them a speed of slightly over 18 knots. Two 4-inch, 50-caliber guns; a 3-inch, 50-caliber antiaircraft gun, and a Y gun depth charge projector made up their major armament. Because of their simple lines they were capable of being built on a mass production basis and this was undertaken at the Ford Motor Company plant at Detroit, Michigan. Of the 100 boats originally contracted for,

60 were finally built. Their six-stage impulse turbines were of a very strong and compact construction, driving the propeller through a reduction gear. This gear was in all probability the most ususual part of the engineering plant, as it comprised a cast iron casing containing a sun and planet gear system, suspiciously reminding one of the old Model " T " Ford car transmission.

Other small craft worthy of mention were the subchasers, small wooden craft 110 feet long, with three propellers each driven by a gasoline engine. Their principal weapon was the depth charge. Accompanied by a mother ship, several of them crossed the ocean under their own power and demonstrated their seaworthiness admirably.

To restore some balance to the life-line of the overseas transportation service, large cargo ship and tanker programs were put forward. The usual design and experimentation that generally accompanies a new vessel and the precise complexity of fabrication had to be set aside. Consequently a type of ship frequently called the " fabricated " or sometimes " Hog Island " ship came into being. The idea is credited to a Mr. C. P. M. Jack, consulting engineer, and by building these vessels of simple form and lines from stem to stern, the lack of cargo ships was eventually met. To finance and administer the program, the government created the Emergency Fleet Corporation. Just prior to our entry in war, 1,718,338 gross tons of ships of all types were under construction, including 500 merchant vessels. For the fiscal year ending in June, 1917, close to 800,000 tons were built. Ships were built of all construction materials available, steel, wood, and even reinforced concrete. It is almost unnecessary to say that the last two were eventual failures, the wooden ships generally being of wood that was too green, and the concrete vessels being unable to withstand the combined racking effects of yawing, rolling, pitching, sagging and hogging in a heavy sea. Labor formed the real problem of shipbuilding, as the supply of that commodity was scarce, and when men were available a considerable training period had to be undergone for the specialized art of shipbuilding.

By July, 1918, a deadweight tonnage of 13,718,350 was under construction in the United States. For these fabricated ships a standard water-tube boiler with cross drums had been devised, also

a standard type of reciprocating engine or turbine. Cast steel anchor chain had arrived and in the list of new developments, Winton introduced a Diesel reduction gear. To operate this huge fleet of merchant ships the government created another organization, the Shipping Board, which administered the fueling, goings and comings of these vessels. One interesting regulation was the requirement that all ships carry a two-day supply of anthracite coal for smokeless steaming through the submarine zone.

One other interesting highlight of the war period was the development and use of electric welding, which had been described in the JOURNAL in 1915. At the outbreak of the War many German vessels were in foreign ports. To avoid capture on the high seas, many remained in port, where they were interned. When the United States declared war in April, 1917, the ships were taken over and the crews placed in concentration camps. Examination of the ships disclosed a considerable amount of vandalism had taken place, in many cases the engines being almost completely wrecked. In some ships, wedges had been driven between the pistons and cylinders, the connecting rods, boiler stays and piston rods were sawed through, and the boilers ruined by dry firing. With the ordinary means available for repair, about a year and a half appeared as the time necessary to accomplish replacement of the cylinders. Of 103 ships seized by our Government, 50 were turned over to the Navy for repairs. After inspecting the damage, naval engineers assigned to the task by Admiral Griffin, Chief of the Bureau of Steam Engineering, recommended repairs by welding. electric or oxyacetylene, or mechanical patches where welding was not possible. While welding repairs were being made, in the face of strong opposition by engine builders and insurance companies, the deterioration caused by long idleness was simultaneously repaired. As these 50 ships were in service for at least a year before the war ended, transporting thousands of troops overseas, the value of rapid repairs (7 to 8 months total) and the wisdom of Admiral Griffin's decision is apparent. The Secretary of the Navy's Annual Report for 1918 lists a year's saving in time, and $20,000,000 in cost.

Of the major war vessels launched and commissioned during the War, the *New Mexico* was the most outstanding because of her

electric drive plant, which at that time was the largest afloat. The propelling machinery, built by General Electric Company, was awarded under contract to cost $431,000. Her commercial predecessors were two Chicago fireboats, the *Joseph Medill* and *Graeme Stewart,* built in 1908. Success of electric drive in the *Jupiter* prompted Admiral Griffin, Engineer-in-Chief of the Navy from 1913 to 1921, to decide in favor of electric drive for battleships and battle cruisers in the face of vigorous political and professional opposition. Contrary to Isherwood's experience with *Wampanoag* fifty years before, the naval service stood behind Admiral Griffin almost to a man.

Following the *New Mexico* came the *Tennessee* and *California,* also with electric drive. The *Tennessee's* (Figure 21) machinery was built by Westinghouse and is unusual in that her starting equipment included large water rheostats consisting of large chambers filled and emptied of brine by a pump. She also had four motors, one on each shaft, each capable of 8375 horsepower continuous overload. Two generators supplied power to the combination and steam was generated by eight boilers, each in a separate cell lying outboard of the machinery spaces. Her sister ship had a General Electric installation similar to that of the *New Mexico,* but with certain improvements. These latter two ships were also the first in the Navy to use the Kingsbury thrust bearing.

Authorized by the Act of August 29, 1916, were our first 16-inch gun battleships, the *Colorado, Maryland, Washington,* and *West Virginia.* These four ships of 32,600 tons displacement were fitted with electric drive on the four screws with a total designed horsepower of 28,900 and were to have a speed of 21 knots. Six months later six battleships of the *South Dakota* class were authorized. These ships marked an increase over their predecessors in that they were to be of 43,200 tons displacement, carry twelve 16-inch guns, and make 23 knots. Their silhouette was also changed from two smokepipes to one. In addition, during these same years, six battle cruisers of 43,500 tons, and designed for 33¼ knots were authorized. Construction began shortly after their authorization, with all drives to be electric. Originally the battle cruisers were designed for 32 boilers of the B&W header type, but before construction was started, 16 express boilers were substituted instead. The 1918 re-

port of the Secretary of the Navy asked for 10 more battleships and 6 battle cruisers for the following three years, and on July first of that year the Navy had in operation and building a total of 2275 vessels.

Signing of the armistice in November, 1918, brought the War to a close and a let-up in the general pressure. Great Britain had by now changed to 15-inch guns, and oil fuel only. The surrendered German fleet was split up and several vessels were turned over to the United States, where they were carefully studied and some used as targets. Naval building programs continued in the victorious countries, and in 1919 the United States was acknowledged the strongest naval power in the world. England had launched itself on a huge battleship program and started the battle cruiser *Hood*. The Japanese laid down the *Mutsu* of 33,800 tons, but left the remainder of their program obscure, though they contended that because of their insular location a large navy was necessary.

Experimentation, too, had gone on with leaps and bounds. Underwater sound transmitters and listening devices appeared; the new battleships acquired selsyn mechanisms for ship and fire control; one-piece gun construction experiments were undertaken; an audio-piloting cable was laid in Ambrose Channel for ships entering New York Harbor; model basin experiments were run with self-propelled models; a turbo-supercharger appeared for aircraft; and the X-ray examination of metals was undertaken. To further pure scientific research in various technical fields, the Naval Experimental and Research Laboratory had been authorized by the Act of August, 1916. The War intervened and construction was temporarily set aside to be picked up again in February, 1920, when a site at Bellevue was selected. Congress also authorized rewards for beneficial suggestions in 1918, to accelerate development along scientific and engineering lines.

However, the gigantic naval race underway overshadowed everything and caused statesmen to hesitate. At the invitation of the President of the United States, a conference of the leading maritime nations was held in Washington during the latter part of 1921 and there England, France, Japan, Italy, and the United States, for the first time in the history of any nations not at war, agreed to

limit their navies to definite dimensions and stop the maddening pace. Building programs everywhere stopped while the Washington Arms Conference was in progress, and from this point on a new aspect was placed on the future development of the navies of the world.

THE APPLICATION OF TENSOR ANALYSIS TO ELECTRICAL CALCULATIONS.

By Doctor Arne Wikstrom, Ph.D.*

Several years ago, Kron applied tensor analysis to the solution of the every day problems of the electrical machinery designer, and in this article, Doctor Wikstrom has attempted to present the application so that it can be understood by designers more familiar with conventional mathematics and who are not familiar with the possibilities of this relatively little known method. After following through the author's presentation, it will be apparent that the real value of the application lies more in the design and study of complex electrical systems such as transmission lines, and carefully balanced power and lighting distribution arrangements, than in the design of particular electrical machines where the factors which vary are more limited. In distributing systems of all kinds, it should be definitely valuable.

The general opinion and belief among electrical engineers is that tensor analysis is difficult to understand and can only be used by a few advanced scholars and not by the practical engineer, who has to deal with machine characteristics and complex algebra. In order to correct this misconception and at the same time give to the reader a fair idea of this so-called "absolute mathematics" some of its fundamental concepts are here developed in a simple language.

Originally tensors started out in n-dimensional geometery. The German mathematician Karl Friedrich Gauss (1777-1855), who was professor at the University of Göttingen, developed a metrical geometry of an ordinary surface from its intrinsic properties, i.e., from properties which for their definition require no elements which lie outside the surface itself. Riemann, also a professor at Göttingen, extended this differential geometery to any number of dimensions.

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Besides Gauss and Riemann, Beltrami, Christoffel and Lipschitz have later contributed to prepare the way for the alegbra and calculus of tensors.

Most of the development is, however, due to the Italian professor G. Ricci (1853-1925), who should be regarded as the founder of the tensor calculus. Levi-Civita, one of Ricci's pupils and later professor in Rome, contributed to Ricci's absolute calculus by introducing the idea of parallelism in connection with the differential geometry of non-Euclidean manifolds. His book, published 1925 in the Italian language, has been translated into English by Miss Margorie Long and published under the title "The Absolute Differential Calculus."

It is to be understood right from the start that tensors can be useful in any problem which can be treated by n equations, whether these are linear or not. It is, however, not possible to benefit from tensors if not at least one equation of a special case can be written and also solved.

Tensors are of particular value when it comes to extending a special problem to a general case. If a solution of some problem of a particular transformer having only one primary and one secondary winding is available, it is possible, by means of tensors, to extend such a problem to a general transformer, which has an arbitrary number of windings. A general solution has the advantage of making it possible to build up circuits and apparatus into combinations which have certain required characteristics.

It should therefore be remembered that tensor analysis makes it possible to keep a problem along general lines but that in itself it is not capable of producing a solution.

Complex Numbers.

In complex vector algebra, now familiar to every electrical engineer, a vector e may be expressed as the sum of a real and an imaginary component. Let the horizontal component be a and real, and the vertical component be b and imaginary, then

$$e = a + jb$$

The operator "j" is placed in front of the vertical component and is therefore a "tag" or symbol which indicates that this com-

ponent must not be "mixed" with the real component. The combination of the two components and the resultant vector represents a certain instant of time, and these vectors are therefore "time-vectors."

In this article voltages and currents are denoted by small letters (e, i) while circuit constants are written with capital letters (R, X, G, Z, Y).

In order to make sure that we know in which conductor a voltage e or a current i is to be found all vectors are to be "tagged." Thus, that a voltage e exists between the terminals of a conductor a is indicated by the symbol e_a. A circuit constant, such as the impedance Z, may carry a current and at the same time have a voltage impressed upon it and must therefore necessarily have two subscripts. Of these the first one indicates in which conductor the voltage is to be found and the second in which one the current exists.

When the current i_b flows in the impedance Z_{ab} the voltage in conductor a is

$$e_a = Z_{ab} i_b$$

or

$$e_a + j e_a' = (R_{ab} + jX_{ab})\ (i_b + j i_b')$$

In general, when two conductors are separated by an insulator, it is not possible to produce a voltage drop in one conductor, due to a current in the other, except by means of mutual induction. Thus a voltage drop due to pure resistance does not exist, and for this reason every impedance with two different subscripts can be written as a reactance or $Z_{ab} = X_{ab}$.

Let three conductors a, b, c have the following constants: Z_{aa}, X_{ab}, X_{ac}; X_{ba}, Z_{bb}, X_{bc}; X_{ca}, X_{cb}, Z_{cc}.

Due to the currents i_a, i_b and i_c *the* voltages e_a, e_b and e_c become:

$$\left.\begin{aligned} e_a &= Z_{aa} i_a + X_{ab} i_b + X_{ac} i_c \quad \text{(a)} \\ e_b &= X_{ba} i_a + Z_{bb} i_b + X_{bc} i_c \quad \text{(b)} \\ e_c &= X_{ca} i_a + X_{cb} i_b + Z_{cc} i_c \quad \text{(c)} \end{aligned}\right\} (1)^*$$

* Notice that here the three voltages e_a, e_b and e_c are time-vectors and therefore the quantities on the right side of the equation are also complex. If equation (1a) is to be written out in detail it should take the form:

$$\begin{aligned} e_a + j e_a' = {} & \{R_{aa} + j[(X_{aa})_L - (X_{aa})_C]\}(i_a + j i_a') + \\ & + j[(X_{ab})_L - (X_{ab})_C](i_b + j i_b') + \\ & + j[(X_{ac})_L - (X_{ac})_C](i_c + j i_c') \end{aligned}$$

Unit Vectors.

As it would be difficult to remember in a numerical problem which conductor the voltage or current refers to, it is found practical to use an additional identification mark, a unit vector, following immediately the voltage or current symbol. These unit vectors are " space vectors " and although they may be of an arbitrary number they are assumed to make right angles with each other. Such a hyperdimensional co-ordinate system can not be visualized geometrically but can nevertheless be used mathematically.

In accordance with this notation a current $i_a\mathbf{a}$ indicates that i_a amperes flow in conductor a. A numerical example such as $10\mathbf{a}$ indicates that a current of 10 amperes flows in conductor a. After an impedance Z_{aa} it is obviously necessary to write two unit vectors, and therefore $10\ \mathbf{aa}$ indicates that if a current i_a flows in conductor a, the voltage drop in this conductor becomes $10i_a$.

Applying this unit-vector notation to equation (1) gives:

$$\left.\begin{aligned} e_a\mathbf{a} &= (Z_{aa}\mathbf{aa}) \cdot (i_a\mathbf{a}) + (X_{ab}\mathbf{ab}) \cdot (i_b\mathbf{b}) + (X_{ac}\mathbf{ac}) \cdot (i_c\mathbf{c}) \\ e_b\mathbf{b} &= (X_{ba}\mathbf{ba}) \cdot (i_a\mathbf{a}) + (Z_{bb}\mathbf{bb}) \cdot (i_b\mathbf{b}) + (X_{bc}\mathbf{bc}) \cdot (i_c\mathbf{c}) \\ e_c\mathbf{c} &= (X_{ca}\mathbf{ca}) \cdot (i_a\mathbf{a}) + (X_{cb}\mathbf{cb}) \cdot (i_b\mathbf{b}) + (Z_{cc}\mathbf{cc}) \cdot (i_c\mathbf{c}) \end{aligned}\right\} (2)$$

In order to further simplify equation (2) the three voltages $e_a\mathbf{a}$, $e_b\mathbf{b}$ and $e_c\mathbf{c}$ are combined in a " vector " $\mathbf{e}$ such that

$$\mathbf{e} = e_a\mathbf{a} + e_b\mathbf{b} + e_c\mathbf{c}$$

The three components of which $\mathbf{e}$ consists are space-vectors and are not necessarily to be added, because the three conductors a, b and c may be connected in a parallel or series-parallel combination. It is best to think of $\mathbf{e}$ as a " symbol " for all voltages of the circuit and not as a summation of the individual components. Later, when the actual tensor notation is explained, we shall see how e_m in a sense indicates all voltages and at the same time any one of the voltages in the circuit.

The Dot Product.

The dot product or scalar product of two vectors $\mathbf{a}$ and $\mathbf{b}$ is defined as

$$\mathbf{a} \cdot \mathbf{b} = ab \cos \emptyset \cdot$$

where $\emptyset$ is the angle between the vectors. An example of a dot product is the electrical power p, which can be written:

$$p = \mathbf{e} \cdot \mathbf{i} = ei \cos \emptyset$$

All unit vectors are assumed to make right angles with each other and therefore

$$\mathbf{a} \cdot \mathbf{a} = a^2 \cos 0 = a^2 = 1$$

$$\mathbf{a} \cdot \mathbf{b} = ab \cos 90 = 0$$

It is further agreed that only those vectors which are nearest to the dot are to be multiplied with each other. Example:

$$(X_{ab}\mathbf{ab}) \cdot (i_a\mathbf{a}) = X_{ab}i_a\mathbf{ab}\cdot\mathbf{a} = 0 \quad \text{because } \mathbf{b}\cdot\mathbf{a} = 0$$

The three equations (2) may now be combined into one equation in the following manner:

$$\left.\begin{matrix} \mathbf{e} = e_a\mathbf{a} + \\ e_b\mathbf{b} + e_c\mathbf{c} = \end{matrix}\right\{\begin{matrix} Z_{aa}\mathbf{aa} + X_{ab}\mathbf{ab} + X_{ac}\mathbf{ac} + \\ + X_{ba}\mathbf{ba} + Z_{bb}\mathbf{bb} + X_{bc}\mathbf{bc} + \\ + X_{ca}\mathbf{ca} + X_{cb}\mathbf{cb} + Z_{cc}\mathbf{cc} \end{matrix}\left.\right\} \cdot (i_a\mathbf{a} + i_b\mathbf{b} + i_c\mathbf{c}) \tag{3}$$

If the combination of all impedances and reactances is written under one single symbol $\mathbf{Z}$ then equation (3) can be simplified into

$$\mathbf{e} = \mathbf{Z} \cdot \mathbf{i} \tag{4}$$

That equations (2) and (3) are identical can easily be verified if all the 27 possible products of the latter are formed. Of these, 18 are equal to zero and therefore only nine remain. When we multiply the first row of $\mathbf{Z}$ in equation (3) by $i_a\mathbf{a}$ the following products are obtained:

$$Z_{aa}\mathbf{aa} \cdot i_a\mathbf{a} = Z_{aa}i_a\mathbf{a} \qquad \text{because } \mathbf{a}\cdot\mathbf{a} = 1$$

$$X_{ab}\mathbf{ab} \cdot i_a\mathbf{a} = X_{ab}i_a\mathbf{ab}\cdot\mathbf{a} = 0 \quad \text{because } \mathbf{b}\cdot\mathbf{a} = 0$$

$$X_{ac}\mathbf{ac} \cdot i_a\mathbf{a} = 0 \qquad \text{because } \mathbf{c}\cdot\mathbf{a} = 0$$

Such an impedance **Z** can be written in a tabular form. This makes it unnecessary to repeat the unit vectors. A table such as equation (5) is called a matrix.

$$\mathbf{Z} = \begin{array}{c|ccc} & \mathbf{a} & \mathbf{b} & \mathbf{c} \\ \hline \mathbf{a} & Z_{aa} & X_{ab} & X_{ac} \\ \mathbf{b} & X_{ba} & Z_{bb} & X_{bc} \\ \mathbf{c} & X_{ca} & X_{cb} & Z_{cc} \end{array} \qquad (5)$$

It was shown above that an impedance Z_{aa} must be followed by two unit vectors written next to each other but without any algebraic sign between them. Such a combination as **aa** of any two vectors is called a dyad. A polynomial of dyads is called a dyadic. From the vectors $\mathbf{A}_1, \mathbf{A}_2, \mathbf{A}_3 \ldots\ldots \mathbf{A}_n$ and $\mathbf{B}_1, \mathbf{B}_2, \mathbf{B}_3, \ldots\ldots$ B_n a dyadic Φ results if:

$$\Phi = \mathbf{A}_1\mathbf{B}_1 + \mathbf{A}_2\mathbf{B}_2 + \mathbf{A}_3\mathbf{B}_3 + \ldots + \mathbf{A}_n\mathbf{B}_n \qquad (6)$$

In order to show that **Z** in equation (5) is a dyadic let equation (6) be written as the sum of nine terms, and every individual vector as the sum of three components, each component consisting of a scalar and a unit vector.

Thus

$$\begin{aligned}
\mathbf{A}_1 &= a_{11}\mathbf{a} + a_{12}\mathbf{b} + a_{13}\mathbf{c} \\
\mathbf{A}_2 &= a_{21}\mathbf{a} + a_{22}\mathbf{b} + a_{23}\mathbf{c} \\
&\ldots\ldots\ldots\ldots\ldots \\
&\ldots\ldots\ldots\ldots\ldots \\
\mathbf{A}_n &= a_{n1}\mathbf{a} + a_{n2}\mathbf{b} + a_{n3}\mathbf{c} \\
\mathbf{B}_1 &= b_{11}\mathbf{a} + b_{12}\mathbf{b} + b_{13}\mathbf{c} \\
\mathbf{B}_2 &= b_{21}\mathbf{a} + b_{22}\mathbf{b} + b_{23}\mathbf{c} \\
&\ldots\ldots\ldots\ldots\ldots \\
&\ldots\ldots\ldots\ldots\ldots \\
\mathbf{B}_n &= b_{n1}\mathbf{a} + b_{n2}\mathbf{b} + b_{n3}\mathbf{c}
\end{aligned}$$

The products $\mathbf{A}_j\mathbf{B}_j$ are therefore:

$$\mathbf{A}_1\mathbf{B}_1 = a_{11}b_{11}\mathbf{aa} + a_{11}b_{12}\mathbf{ab} + a_{11}b_{13}\mathbf{ac} + a_{12}b_{11}\mathbf{ba} + a_{12}b_{12}\mathbf{bb} + \\ + a_{12}b_{13}\mathbf{bc} + a_{13}b_{11}\mathbf{ca} + a_{13}b_{12}\mathbf{cb} + a_{13}b_{13}\mathbf{cc}$$

$$\mathbf{A}_2\mathbf{B}_2 = a_{21}b_{21}\mathbf{aa} + a_{21}b_{22}\mathbf{ab} + \ldots\ldots\ldots\ldots$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$\mathbf{A}_n\mathbf{B}_n = a_{n1}b_{n1}\mathbf{aa} + a_{n1}b_{n2}\mathbf{ab} + \ldots\ldots\ldots\ldots$$

If the coefficients of identical dyads are added, Φ can be expressed as the sum of nine dyads:

$$\Phi = (a_{11}b_{11} + a_{21}b_{21} + \ldots\ldots\ldots\ldots + a_{n1}b_{n1})\,\mathbf{aa} + \\ + (a_{11}b_{12} + a_{21}b_{22} + \ldots\ldots\ldots\ldots + a_{n1}b_{n2})\,\mathbf{ab} +$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$+ (a_{13}b_{13} + a_{23}b_{23} + \ldots\ldots\ldots\ldots + a_{n3}b_{n3})\,\mathbf{cc}$$

and a dyadic Φ can therefore be written in tabular form as a matrix

$$\Phi = \begin{array}{c|ccc} & \mathbf{a} & \mathbf{b} & \mathbf{c} \\ \hline \mathbf{a} & a_{aa} & a_{ab} & a_{ac} \\ \mathbf{b} & a_{ba} & a_{bb} & a_{bc} \\ \mathbf{c} & a_{ca} & a_{cb} & a_{cc} \end{array} \qquad (7)$$

Equation (7) which equally well could express $\mathbf{Z}$ is a dyadic where

$$\mathbf{a}_{aa} = a_{11}b_{11} + a_{21}b_{21} + \ldots\ldots\ldots\ldots + a_{n1}b_{n1} = \sum_{j=1}^{n} a_{j1}\,b_{j1}$$

Polyadics.

A scalar, which is defined by three unit vectors written next to each other, is called a *triadic*. If written in tabular form such a table becomes a cube divided into an array of many small cells.

If a scalar is identified by more than three unit vectors it is said to be a *polyadic*.

In the following is shown how addition, subtraction, multiplication and division of vectors, dyadics, etc., is performed.

Addition and Subtraction

can only take place between like quantities identified by the same unit vectors, which are arranged in the same sequence. Thus, the voltages 10**a** and 12**a** if added become 22**a** while 10**a** added to 12**b** is still 10**a** + 12**b**.

The Product of Two Vectors.

The power p in an electric circuit is the dot product of the voltage and the current.

$$\begin{aligned} p = \mathbf{e}\cdot\mathbf{i} &= (e_a\mathbf{a} + e_b\mathbf{b} + e_c\mathbf{c})\cdot(i_a\mathbf{a} + i_b\mathbf{b} + i_c\mathbf{c}) + \\ &= e_a i_a \mathbf{aa} + e_b i_b \mathbf{bb} + e_c i_c \mathbf{cc} = \\ &= e_a i_a + e_b i_b + e_c i_c \end{aligned} \tag{8}$$

All the other possible products are zero, for instance

$$e_a\mathbf{a}\cdot i_b\mathbf{b} = e_a i_b \mathbf{a}\cdot\mathbf{b} = 0 \quad \text{because } \mathbf{a}\cdot\mathbf{b} = 0$$

It is obvious from equation (8) that the dot product of two vectors is the scalar value obtained if the scalars of similar components are multiplied in pairs and these products are added.

The Product of Two Matrices.

In order to multiply two matrices, the dot product of two dyads must first be defined. Let the two dyads be $\mathbf{A}_1\mathbf{B}_1$ and $\mathbf{A}_2\mathbf{B}_2$. Their dot product is defined as

$$(\mathbf{A}_1\mathbf{B}_1)\cdot(\mathbf{A}_2\mathbf{B}_2) = \mathbf{B}_1\cdot\mathbf{A}_2\,(\mathbf{A}_1\mathbf{B}_2)$$

Thus the dot product of two dyads is a dyad, consisting of the first and the last vector, which has a scalar equal to the dot product of the second and the third vector.

The product of two matrices

$$\Phi_1 \cdot \Phi_2 = \begin{array}{c|ccc} & \mathbf{a} & \mathbf{b} & \mathbf{c} \\ \hline \mathbf{a} & A_{aa} & A_{ab} & A_{ac} \\ \mathbf{b} & A_{ba} & A_{bb} & A_{bc} \\ \mathbf{c} & A_{ca} & A_{cb} & A_{cc} \end{array} \cdot \begin{array}{c|ccc} & \mathbf{a} & \mathbf{b} & \mathbf{c} \\ \hline \mathbf{a} & B_{aa} & B_{ab} & B_{ac} \\ \mathbf{b} & B_{ba} & B_{bb} & B_{bc} \\ \mathbf{c} & B_{ca} & B_{cb} & B_{cc} \end{array}$$

is obtained by multiplying each dyad in one dyadic with each and every dyad in the other dyadic. Most of these products are identical to zero, and the remaining products can be combined into nine dyads. Thus the product itself is a dyadic.

Multiplying the first row of Φ_1 with the first column of Φ_2 gives

$$\begin{aligned} A_{aa}\mathbf{aa} \cdot B_{aa}\mathbf{aa} &= A_{aa}B_{aa}\,\mathbf{a} \cdot \mathbf{a}\,\mathbf{aa} = A_{aa}B_{aa}\mathbf{aa} \\ A_{ab}\mathbf{ab} \cdot B_{ba}\mathbf{ba} &= A_{ab}B_{ba}\,\mathbf{aa} \\ A_{ac}\mathbf{ac} \cdot B_{ca}\mathbf{ca} &= A_{ac}B_{ca}\,\mathbf{aa} \end{aligned}$$

The rest of the products between the first row of Φ_1 and the first column of Φ_2 are all equal to zero.

Example: $A_{aa}\mathbf{aa} \cdot B_{ba}\mathbf{ba} = A_{aa}B_{ba}\,\mathbf{a} \cdot \mathbf{b}\,\mathbf{aa} = 0$

The result of this multiplication is therefore three dyads, each of which consists of two unit vectors **aa**, and for this reason the sum of these dyads in the new dyadic is to be placed in its upper left-hand corner.

In general, in order to obtain the dyad C_{rs} in the new dyadic, multiply the numbers in the *r-row* of the first dyadic with the numbers of the *s-column* of the second dyadic and add these products.

A numerical example will help to clarify this rule.

$\Phi_1 \cdot \Phi_2 = \mathbf{b}$

	a	b	c
a	2	3	5
b	3	4	3
c	6	8	5

$\cdot$

	a	b	c
a	7	4	3
b	4	9	8
c	2	2	6

$= \mathbf{b}$

	a	b	c
a	36	45	60
b	43	54	59
c	84	106	112

The value in the *a-row* and *a-column* of the new matris is equal to 36 because:

$$2 \times 7 + 3 \times 4 + 5 \times 2 = 14 + 12 + 10 = 36$$

In a similar way all the other numbers may be calculated.

The Product of a Matrix and a Vector

is a vector. The calculation is performed in a similar way. Example:

	a	b	c
a	2	3	5
b	3	4	3
c	6	8	5

$\cdot$

a	7
b	4
c	2

$=$

a	36
b	43
c	84

Changing the Order of the Factors in a Dot Product

is in general not permissible.

Thus $X_{ab}\mathbf{ab} \cdot i_b\mathbf{b} = X_{ab}i_b\mathbf{a}$ because $\mathbf{b} \cdot \mathbf{b} = 1$

while $i_b\mathbf{b} \cdot X_{ab}\mathbf{ab} = 0$ because $\mathbf{b} \cdot \mathbf{a} = 0$

The Transpose of a Dyadic.

If in a dyadic Φ rows and columns are interchanged, the transpose Φ_t of the dyadic is formed. It can easily be shown that the dot

product of a dyadic and a vector is equal to the dot product of the same vector and the transpose of the dyadic. In other words, when the sequence of the terms in the dot product of a vector and a dyadic are interchanged the dyadic must be replaced by the transpose dyadic.

$$\Phi \cdot \mathbf{e} = \begin{vmatrix} A & B & C \\ D & E & F \\ G & H & I \end{vmatrix} \cdot \begin{vmatrix} K \\ L \\ M \end{vmatrix} = \begin{vmatrix} N \\ O \\ P \end{vmatrix}$$

where

$$N = AK + BL + CM$$
$$O = DK + EL + FM$$
$$P = GK + HL + IM$$

Reversing the order of the dot product and at the same time replacing the dyadic Φ by its transpose Φ_t gives

$$\mathbf{e} \cdot \Phi_t = \begin{vmatrix} K & L & M \end{vmatrix} \cdot \begin{vmatrix} A & D & G \\ B & E & H \\ C & F & I \end{vmatrix} = \begin{vmatrix} Q & R & S \end{vmatrix}$$

where

$$Q = KA + LB + MC = N$$
$$R = KD + LE + MF = O$$
$$S = KG + LH + MI = P$$

Hence: $$\Phi \cdot \mathbf{e} = \mathbf{e} \cdot \Phi_t \qquad (9)$$

Division with a Dyadic

is done by multiplying with its inverse dyadic. Hence, in order to solve the equation

$$\mathbf{e} = \mathbf{Z} \cdot \mathbf{i}$$

with respect to $\mathbf{i}$, both sides of the equation are multiplied by $\mathbf{Z}^{-1}$

$$\mathbf{Z}^{-1} \cdot \mathbf{e} = \mathbf{Z}^{-1} \cdot \mathbf{Z} \cdot \mathbf{i}$$

or if

$$\mathbf{Z}^{-1} \cdot \mathbf{Z} = \text{unity}$$

$$\mathbf{i} = \mathbf{Z}^{-1} \cdot \mathbf{e}$$

It remains now to show how $\mathbf{Z}^{-1}$ can be calculated if $\mathbf{Z}$ is given.

Let us solve equations (2) with respect to $i_a\mathbf{a}$, $i_b\mathbf{b}$ and $i_c\mathbf{c}$ using the theory of determinants.

The first step is to find the main determinant D

$$D = \begin{Bmatrix} Z_{aa} & X_{ab} & X_{ac} \\ X_{ba} & Z_{bb} & X_{bc} \\ X_{ca} & X_{cb} & Z_{cc} \end{Bmatrix}$$

Let now $\mathbf{D}_{aa}$, $\mathbf{D}_{bb}$ and $\mathbf{D}_{cc}$ represent those determinants which can be found from D if the first, second and third columns, respectively are replaced by $e_a\mathbf{a}$, $e_b\mathbf{b}$ and $e_c\mathbf{c}$.

Thus

$$\mathbf{D}_{aa} = \begin{Bmatrix} e_a\mathbf{a} & X_{ab} & X_{ac} \\ e_b\mathbf{b} & Z_{bb} & X_{bc} \\ e_c\mathbf{c} & X_{cb} & Z_{cc} \end{Bmatrix}$$

If this determinant is developed along the first column the result can be written:

$$\mathbf{D}_{aa} = e_a\mathbf{a} \begin{Bmatrix} Z_{bb} & X_{bc} \\ X_{cb} & Z_{cc} \end{Bmatrix} - e_b\mathbf{b} \begin{Bmatrix} X_{ab} & X_{ac} \\ X_{cb} & Z_{cc} \end{Bmatrix} + e_c\mathbf{c} \begin{Bmatrix} X_{ab} & X_{ac} \\ Z_{bb} & X_{bc} \end{Bmatrix}$$

$$\mathbf{D}_{aa} = e_a\mathbf{a}\,(Z_{bb}Z_{cc} - X_{cb}X_{bc}) - e_b\mathbf{b}\,(X_{cb}Z_{cc} - X_{cb}X_{ac}) + \\ + e_c\mathbf{c}\,(X_{ab}X_{bc} - Z_{bb}X_{ac})$$

The solution wanted is:

$$i_a\mathbf{a} = \frac{\mathbf{D}_{aa}}{D} = e_a\mathbf{a}\,\frac{D_{aa}}{D} - e_b\mathbf{b}\,\frac{D_{ab}}{D} + e_c\mathbf{c}\,\frac{D_{ac}}{D}$$

Notice that $\mathbf{D}_{aa}$ is a vector while D_{aa} is the numerical value of the *minor* determinant, which is obtained from the *main* determinant by omitting its a-row and a-column. By solving $i_b\mathbf{b}$ and $i_c\mathbf{c}$ in a similar way, it is obvious that $\mathbf{Z}^{-1}$ can be determined from $\mathbf{Z}$ by making use of the following rule:

> In order to find $\mathbf{Z}^{-1}$ from $\mathbf{Z}$, interchange columns and rows of the *main* determinant obtained from the terms of the impedance matrix. The value of the element in row r and column s of the inverse impedance matrix is then found by omitting row r and column s of the main determinant and dividing this minor determinant by the value of the main determinant.

In the following example the inverse impedance matrix $\mathbf{Z}^{-1}$ is found from $\mathbf{Z}$.

$\mathbf{Z} =$

	a	b	c
a	2	3	4
b	4	5	3
c	7	2	6

$$D_{aa} = \begin{Bmatrix} 5 & 3 \\ 2 & 6 \end{Bmatrix} = 30 - 6 = 24$$

$D_{ab} = 3$

$D_{ac} = -27$ $\qquad D = -69$

Etc.

If all these calculations are carried out and the results are arranged in matrix form, the following inverse impedance matrix is obtained:

$$\mathbf{Z}^{-1} = \begin{array}{c|ccc} & \mathbf{a} & \mathbf{b} & \mathbf{c} \\ \hline \mathbf{a} & -\frac{24}{69} & +\frac{3}{69} & +\frac{27}{69} \\ \mathbf{b} & -\frac{10}{69} & +\frac{16}{69} & -\frac{17}{69} \\ \mathbf{c} & +\frac{11}{69} & -\frac{10}{69} & +\frac{2}{69} \end{array}$$

Above is shown how calculations involving vectors, dyadics, etc., are carried out. Although many other mathematical operations remain to be learned, we shall now concentrate on some of the points which reveal the true nature and purpose of this notation.

It has previously been mentioned that tensor analysis represents a method by which general solutions of problems may be obtained. By using a " stenographic " notation it is further possible to reduce the labor of writing equations to an absolute minimum.

Take as an example the equation

$$\mathbf{e} = \mathbf{Z} \cdot \mathbf{i} \qquad (10)$$

which may represent many different components of **e**, **i** and **Z**. As a matter of fact, it is obvious that equation (10) represents a " general machine " with any number of conductors in any combination, provided these conductors are at rest and that no " foreign

electromotive forces" are present, such as the counter e. m. f. of a machine or a battery, thermal and contact e. m. fs., etc. The reason for restricting equation (10) in this manner is simply that no provision was made for such e. m. fs. in the original set of equations. [See equations (2).]

Equation (10) can be solved either by solving equations (2) simultaneously or by writing the symbolic equation

$$\mathbf{i} = \mathbf{Z}^{-1} \cdot \mathbf{e} \qquad (11)$$

If now the purpose of the whole problem was to find **i**, then equation (11) has naturally not brought the problem closer to a solution; since $\mathbf{Z}^{-1}$ must be calculated, and that again is the same as solving for the different components of **i** in equations (2). Sometimes, however, equation (11) is only an intermediate step in a long series of calculations and it may therefore be definitely advantageous not to calculate $\mathbf{Z}^{-1}$. Such a calculation obviously only blurs the results. Besides, it is possible that during the development $\mathbf{Z}^{-1}$ disappears, for instance by being multiplied by **Z** because

$$\mathbf{Z}^{-1} \cdot \mathbf{Z} = \text{unity} = \mathbf{I} \cdot$$

Here **I** stands for the "idemfactor," which is a matrix where every term is zero except the diagonal ones.

However, the gain in time and labor is only partly responsible for the true value of tensor analysis. The greatest advantage is probably that from an equation of a "general machine" all the special solutions representing "special machines," which belong to the same "group," can be obtained. The different elements of such a "general machine" are interconnected by means of a "transformation matrix" leaving as a result the special case. Such a transformation matrix reduces the generality of the problem, but the resultant equation represents a special diagram of connections. Other diagrams require other transformation matrices. These all consist of tables which indicate how, for instance, a current in the general case should be changed into a current in the special case.

An Example of a Transformation Matrix.

In order to explain the functioning of a transformation matrix, assume that three conductors a, b, c carry the currents $i_a\mathbf{a}$, $i_b\mathbf{b}$ and $i_c\mathbf{c}$, respectively. (See Figure 1.)

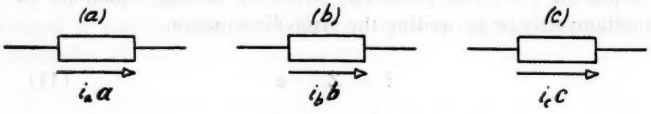

Figure 1

Between the terminals of these conductors the voltages $e_a\mathbf{a}$, $e_b\mathbf{b}$ and $e_c\mathbf{c}$ exist.

Let now the conductors be connected as per Figure 2 and moreover let the currents now be $i_h\mathbf{h}$, $i_f\mathbf{f}$ *and* $i_k\mathbf{k}$.

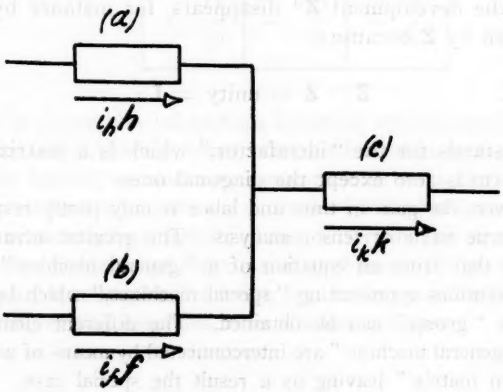

Figure 2

From Figure 2 it is obvious that

$$i_k\mathbf{k} = i_h\mathbf{h} + i_f\mathbf{f}$$

and that therefore the transformation from Figure 1 to Figure 2 can be represented by the following set of equations:

$$\left.\begin{aligned} i_a\mathbf{a} &= i_h\mathbf{h} \\ i_b\mathbf{b} &= \quad\; i_f\mathbf{f} \\ i_c\mathbf{c} &= i_h\mathbf{h} + i_f\mathbf{f} \end{aligned}\right\} \tag{12}$$

or

$$\mathbf{C} = \begin{array}{c|cc} & \mathbf{h} & \mathbf{f} \\ \mathbf{a} & 1 & 0 \\ \mathbf{b} & 0 & 1 \\ \mathbf{c} & 1 & 1 \end{array}$$

where **C** is called the transformation matrix. Algebraically we may write:

$$\mathbf{i} = \mathbf{C} \cdot \mathbf{i}' \tag{13}$$

where **i** represents the currents in the general case and **i'** the currents in the special case.

The reader should notice that there is a distinct difference between an impedance matrix and a transformation matrix. The former is a connecting link between two different vectors, for instance **e** and **i**, both belonging to the same system of co-ordinate axes; while the latter connects similar vectors which belong to different systems of co-ordinate axes.

In accordance with equations (12) the currents in the different conductors are unchanged after the transformation: $i_a\mathbf{a} = i_h\mathbf{h}$, etc. Thus the power in two circuits is the same. This is also expressed by saying that the power is an "invariant" under the transformation. (An invariant function is a function of the coefficients of a quantic which retains its form when transformed linearly.)

If the total power is P before the transformation and P' after, then:

$$P = P' = \mathbf{e} \cdot \mathbf{i} = \mathbf{e}' \cdot \mathbf{i}' \tag{14}$$

From equation (13)

$$\mathbf{i} = \mathbf{C} \cdot \mathbf{i}'$$

and therefore

$$P = \mathbf{e} \cdot \mathbf{i} = \mathbf{e} \cdot \mathbf{C} \cdot \mathbf{i}'$$

But equation (9) gives:

$$\mathbf{e} \cdot \mathbf{C} = \mathbf{C}_t \cdot \mathbf{e}$$

and therefore

$$P = \mathbf{C}_t \cdot \mathbf{e} \cdot \mathbf{i}' = \mathbf{e}' \cdot \mathbf{i}'$$

If in the last equation $\mathbf{i}'$ is eliminated,

$$\mathbf{C}_t \cdot \mathbf{e} = \mathbf{e}'$$

or

$$\mathbf{e} = \mathbf{C}_t^{-1} \cdot \mathbf{e}' \tag{15}$$

From equations (13) and (15) it is obvious that current and voltage transform in different ways. The physical explanation is that when conductors are connected in series the currents are the same and the voltages are added, while in parallel connection the voltages are identical and the currents are added. Current and voltage therefore transform in an inverse manner.

Even the impedance $\mathbf{Z}$ changes when the transformation from Figure 1 to Figure 2 takes place.

Originally the equation was

$$\mathbf{e} = \mathbf{Z} \cdot \mathbf{i} \tag{16}$$

Using equations (14) and (15) makes it possible to eliminate $\mathbf{e}$ and $\mathbf{i}$ and express equation (16) in terms of $\mathbf{e}'$ and $\mathbf{i}'$.

Thus

$$\mathbf{C}_t^{-1} \cdot \mathbf{e}' = \mathbf{Z} \cdot \mathbf{C} \cdot \mathbf{i}'$$

or

$$\mathbf{e}' = \mathbf{C}_t \cdot \mathbf{Z} \cdot \mathbf{C} \cdot \mathbf{i}' \tag{17}$$

However, equation (17) in the new system should be written

$$\mathbf{e}' = \mathbf{Z}' \cdot \mathbf{i}' \tag{18}$$

and therefore $\mathbf{Z}'$ in equation (18) may be represented by

$$\mathbf{Z}' = \mathbf{C}_t \cdot \mathbf{Z} \cdot \mathbf{C} \tag{19}$$

The value of $\mathbf{Z}'$ is calculated in such a way that first the product $\mathbf{C}_t \cdot \mathbf{Z}$ is calculated and then this product is multiplied by $\mathbf{C}$. These calculations are all done in the same way that the products of vectors and matrices were performed.

The above notation represents the so-called *dyadic* notation. Although strictly not a tensor notation it serves as an introduction to the much more useful

Tensor Notation.

Going back to equation (1a) it is obvious that e_a can be written as

$$e_a = \sum_{n=a}^{c} Z_{an} i_n \tag{20}$$

where the lower index n takes the values a, b and c in succession. Thus equation (20) becomes identical to equation (1a) because $Z_{ab} = X_{ab}$.

If the voltage $\mathbf{e}$, which in a way represents the sum of e_a, e_b and e_c, is wanted, the equation may be written

$$e_m = \sum_{m=a}^{c} \sum_{n=a}^{c} Z_{mn} i_n$$

If on the other hand e_m is to represent any one of the three "vectors" e_a, e_b or e_c, depending upon which letter is substituted for m, then only one summation sign is necessary, because

$$e_m = \sum_{n=a}^{c} Z_{mn} i_n \qquad (21)$$

then expresses any one of the three components e_a, e_b and e_c, and therefore in a sense all three as the components were not to be added, anyway.

From equation (21) it is obvious that the summation is always to be undertaken with respect to that index n, which is represented in two places. For this reason it is always obvious when summation is to be undertaken and therefore Σ is superfluous.

Equation (16) which is written in dyadic notation is therefore in tensor notation changed to:

$$e_m = Z_{mn} i_n \qquad (22)$$

It is obvious that in this case the dyadic notation is more simple, requiring no subscripts. However, this is true only where the equations are linear or very simple quadratic ones. In more complicated cases it is impossible to use the dyadic notation.

It is mentioned above that current and voltage are related to each other in an inverse manner. In order to keep this in mind the tensor notation always uses a lower index for the voltage (e_m) and an upper index for the current (i^m). The voltage (e_m) is said to be a "covariant vector," i. e., a function of both coefficients and variables of quantities which maintain their form when the quantity is transformed linearly, while the current (i^m) is said to be "contravariant." The current (i^m) is always assumed to be the variable and has therefore always an upper index.

Voltages are always written horizontally

$$e_m = \begin{array}{|c|c|c|} \multicolumn{1}{c}{a} & \multicolumn{1}{c}{b} & \multicolumn{1}{c}{c} \\ \hline e_a & e_b & e_c \\ \hline \end{array} \text{ or } (e_a, e_b, e_c)$$

while currents are written in a vertical manner

$$i^{m} = \begin{matrix} a \\ b \\ c \end{matrix} \begin{vmatrix} i_a \\ i_b \\ i_c \end{vmatrix} \quad \text{or} \quad \begin{pmatrix} i_a \\ i_b \\ i_c \end{pmatrix}$$

Transformation Equations in Tensor Notation.

(a) Impedances may accordingly have upper and lower indici in four different combinations. Thus it is possible that **Z** may be written in any one of the following ways: Z_{mn}, $Z^{n}_{m.}$, $Z^{m.}_{.n}$ or Z^{mn}. (The dots indicate only the order between indici.)

(b) Different alphabets are used for old and new co-ordinate systems. The transformation matrix **C** is written C^{m}_{a}, indicating that it changes the current i^{a} to the current i^{m} and therefore in tensor notation, equation (13) is written

$$i^{m} = i^{a} C^{m}_{a}$$

(c) The inverse, transpose transformation matrix $\mathbf{C}_{t}^{-1}$ is written C^{a}_{m} without any indication as to which index comes first. Thus, equation (15) is written

$$e_{m} = e_{a} C^{a}_{m}$$

(d) An inverse impedance dyadic $\mathbf{Z}^{-1}$ is written Y^{nm}, if the impedance itself is Z_{mn}. The fact that the inverse impedance is wanted is expressed by using the letter Y, the symbol for admittance. Besides changing a lower index to an upper and vice versa the sequence between indici is changed, i e., from $m \rightarrow n$ in Z_{mn} to $n \rightarrow m$ in Y^{nm}. This corresponds in the dyadic notation to changing the order of the unit vectors.

The polyadics in a tensor equation may come in any order without that the meaning of the equation is changed. This is illustrated by equation (19), which in tensor notation reads

$$Z_{\alpha\beta} = Z_{mn} C^{m}_{\alpha} C^{n}_{\beta}$$

The reader who wishes to obtain further information on this subject is referred to Gabriel Kron's articles in General Electric Review beginning in Volume 38, No. 4, Page 18, April, 1935. Another source of fundamental information may be found in Vector Analysis by A. P. Wills (Prentice-Hall, Inc., 1931). Since the first appearance of Kron's articles, several articles are to be found in leading technical journals. The author has made use of above mentioned literature quite freely.

THE ANCESTORS OF OUR PRESENT PUMPS.

By Lieutenant Commander Rupert M. Zimmerli,
U. S. Navy, Member.*

"It is a cruel mortification, in searching for what is instructive in the history of past times, to find the exploits of conquerors who have desolated the earth, and the freaks of tyrants who have rendered nations unhappy, are recorded with minute and often disgusting accuracy—while the discovery of the useful arts, and the progress of the most beneficial branches of commerce, are passed over in silence, and suffered to sink into oblivion."—Robertson's India.

INTRODUCTION.

The pump which is fundamentally a machine for raising water, is the oldest machine known to man. Back in the dim dawn of history before our ancestors had emerged from the "age of the hunter" and progressed to the "shepherd age," they had learned to lift water for drinking in the cupped hollow of their hands. This was undoubtedly the first positive displacement pump. As man progressed from hunter to shepherd, from shepherd to farmer and from farmer to townsman, the necessity of raising water in ever increasing quantities arose. This necessity became the mother of invention and it is to the ancients that we look for early forms of water raising devices since if there was one art of more importance than another to the early inhabitants of *Central Asia* and the *Valley of the Nile*, it was that of raising water for agricultural purposes. Not merely their general welfare, but their very existence depended upon the artificial irrigation of the land; hence their ingenuity was early directed to the construction of machines for this purpose; and they were stimulated in devising them by the most powerful of all inducements.

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We are inclined to believe that the hydraulic machines of the Assyrians, Babylonians, Persians, and Egyptians have all, or nearly all, come down to us. Most of them have been continued in uninterrupted use in those countries to the present times; while others have reached us through the Greeks and Romans, Saracens and Moors; or, have been obtained in modern days from China and Hindustan.

It is remarkable that almost all machines for raising water originated with the older nations of the world; neither the Greeks (if the screw of Conon be excepted, and even it was invented in Egypt), nor the Romans added a single one to the ancient stock; nor is this surprising, for with few exceptions, those in use at the present day are either identical with or but modifications of those of the ancients.

In their search for water, which is ever so necessary to human life, the ancients soon learned to dig wells. Some wells had stairs descending to the water level, others had none; hence the necessity of some mode of raising the water. From the earliest ages, a vessel suspended to a cord has been used by all nations, a device more simple and more extensively employed than any other, and one which was undoubtedly the germ of the most useful hydraulic machines of the ancients, as the chain of pots, chain pump, etc.

Whenever we attempt to penetrate that obscurity which conceals from our view the works of the ancients, we are led to regret that some of their *mechanics* did not undertake, for the sake of posterity and their own fame, to write a history and description of their machines and manufactures.

ALTERNATING AND CONTINUOUS MOTION PUMPS.

One of the earliest machines for raising water is the *Swape* or Egyptian *Shadoof*. Its inception is shrouded in antiquity although the remains of one was found in an ancient tomb at Thebes, in addition to which they are represented in sculptures which date from 1532 to 1550 B. C., a period extending beyond the Exodus.

The *Shadoof* is merely a long pole weighted at one end and free to turn around a horizontal log which is held a few feet off the ground by posts or a crotch of a convenient tree. To the unweighted end of the long pole an earthen jar suspended by a cord

is attached. By raising the weighted end the jar is dipped into the nearby stream or well and by lowering the weighted end the jar is brought up to the laborer. The weight acts to assist the workmen in raising the jar and prevents the jar from being lowered too quickly. Some *Shadoofs* were arranged with a walk along the pole so that a man could walk back and forth and thus alternately raise and lower the jar. Buckley states that the experiments of Wilson showed that two men could lift 51,600 cubic feet through a height of one foot in ten hours, while one man could lift 33,000 cubic feet under the same conditions.

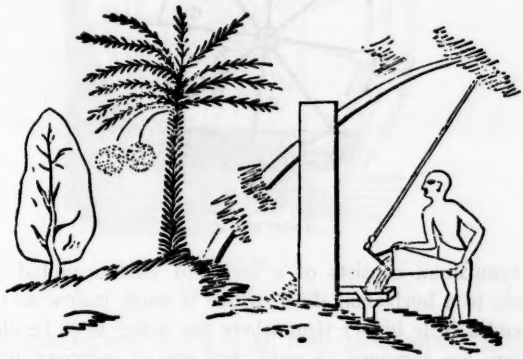

FIGURE 1.

EGYPTIAN SHADOOF EMPLOYED IN WATERING A GARDEN. 1550 B. C.

Passing from the Swape or Shadoof which employed alternating motion we proceed to others more complex, particularly to such as revolve round the centers from which they are suspended, and which have a continuous motion. Although differing in these respects and in their form from the Swape, they will be found essentially the same; their change of figure being more apparent than real, and merely consequent on the new movement imparted to them. As these machines are obviously of later date than the preceding, it may perhaps be supposed that the period of their introduction might be ascertained; but so it is that with scarcely an exception, the time when, place where, and the persons by whom they were invented, are absolutely unknown.

About the beginning of the Christian era a Roman architect and engineer published a treatise on those professions in which he inserted a brief description of some hydraulic engines. This is the only ancient work extant which treats professedly on them and even here the information is meager. The machines described by Vitruvius—for it is to him we allude—are the *Tympanum, Noria, Chain of Pots,* the *Screw* and the *Machine of Ctesibius* or *Pump.*

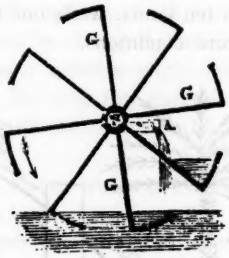

FIGURE 2.
TYMPANUM.

The tympanum consists of a series of gutters united at their open ends to a horizontal shaft, which is made hollow at one end and placed a little higher than where the water is to be elevated; the gutters are arranged as radii, and are of sufficient length to extend from the shaft to a short distance below the surface of the water, each gutter as it revolves scoops up a portion of water and elevates it, till by the inclination to the axle it flows towards the latter, and is discharged through one end of it.

The *Noria* may be considered as a number of revolving swapes. It consists of a series of poles like the arms of a wheel to a horizontal shaft. To the extremity of each, a vessel is attached, which fills as it dips into the water and is discharged into a reservoir or gutter at the upper part of the circle it describes. The idea of thus connecting a number of poles with their buckets must have early occurred to the agricultural machinists of Asia. The Chinese claim to have used the Noria one thousand years before the Christian era and to be able to raise a hundred and fifty tons to the height of forty feet in twenty-four hours. The antiquity of the Noria may

be inferred from its name of "Egyptian Wheel," the only one by which it was known in some countries. It is to be found, if we mistake not, among the symbols of ancient mythology.

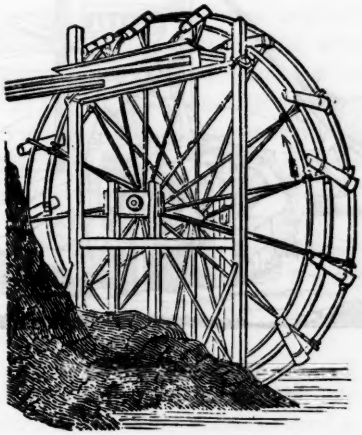

FIGURE 3.
CHINESE NORIA.

The tympanum and Noria in all their modifications have been considered as originating in the gutter, and the swape; while the machine we are now to examine is evidently derived from the primitive cord and bucket. The first improvement of the latter was the introduction of a pulley over which the cord was directed—the next was the addition of another vessel, so as to have one at each end of the rope, and the last and most important consisted in uniting the ends of the rope and securing to it a number of vessels at equal distances through the whole of its length—and the *chain of pots* was the result.

The chain of pots in Egypt is named the *Sakia*. Its superiority over the Noria and Tympanum in being adapted to raise water from every depth has caused it to be more extensively employed for artificial irrigation than any other Egyptian machine. It was probably the "pump" which according to tradition *Danaus* introduced into Greece a thousand years before the building of Babylon by the

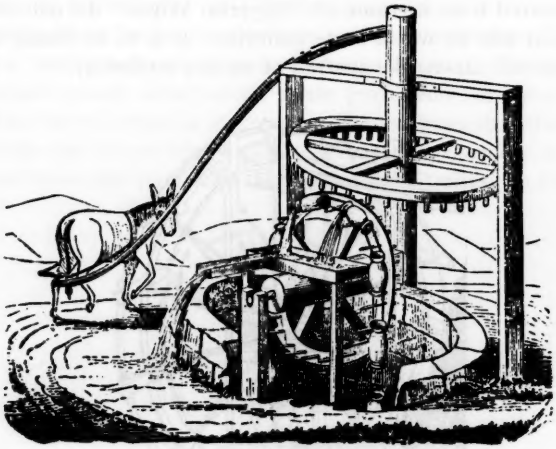

FIGURE 4.
SPANISH CHAIN OF POTS.

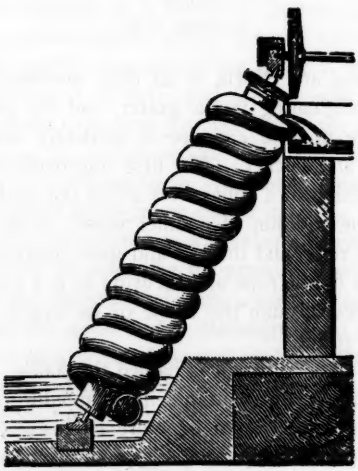

FIGURE 5.
SCREW.

Persians. It is said the Greeks did not at that time possess the knowledge of obtaining water from wells, the companions of Danaus having been the first to dig them and to introduce *pumps*.

The *Cochleon* or Egyptian screw, the machine next described by Vitruvius, is, in every respect, the most original one of which he has given an account. Unlike the preceding, which appear to have been in a great measure deduced from each other, it forms a species of itself; and whoever was its inventor, he has left in it a proof of his genius and a lasting monument of his skill. If it be not the earliest hydraulic engine that was composed of tubes, or in the construction of which they were introduced, it certainly is the oldest one known of that description; and in its mode of operation it differs essentially from all other ancient tube machines; in the latter the tubes merely serve as conduits for the ascending water and as such are at rest, while in the screw, it is the tubes themselves in motion that raise the liquid.

This machine has been constructed in a variety of ways. Sometimes by winding, in the manner of a screw, one or more flexible tubes (generally lead or strong leather) round a cylinder of wood or iron. This cylinder is sustained by gudgeons in such a position that at whatever angle with the horizon it is used, the plane of the helix must always be inclined to its axis at a greater angle; otherwise no water could be raised by it any more than by turning it in the wrong direction. The lower end being immersed in water, the liquid enters the tube and is gradually raised by each revolution until it is discharged above. Instead of tubes wound round a cylinder, large grooves were sometimes formed in the latter and covered by boards or sheets of metal, closely nailed to the surfaces between the grooves—so that the latter might be considered as tubes sunk into the cylinder, instead of being folded round its exterior.

All the ancient machines hitherto examined have come down from periods so extremely remote that not a single circumstance connected with their origin or their authors has been preserved. The screw is the first machine for raising water, whose inventor, or alleged inventor, has been named; and yet, from the imperfect and mutilated state or such ancient writings that incidentally mention it, and the loss of others which treated professedly on it, the ques-

tion of its origin is far from being settled, although it is usually attributed to Archimedes and has long been named after him.

The chain pump, although not described by Vitruvius, is introduced at this place because it seems to be the connecting link between the chain of pots and the machine of Ctesibius. It may be deemed of little consequence to ascertain the circumstances which led to the invention of the chain pump, yet a knowledge of the period when this took place would be of more than usual interest, on account of the analogy between it and the ordinary pump, and of

FIGURE 6.
CHINESE CHAIN PUMP.

the relationship that appears to exist between them. But to what ancient people are we to look for its authors? Not to the Hindoos, or the Egyptians, for it is incredible that either of these people should have lost it if it was ever in their possession. Nor does it appear to have been known to the Greeks; for their navigators would never have employed the screw as a ship pump if they had been acquainted with this machine. But if the Greeks had the

chain pump, the Romans would have received it from them; whereas from the silence of Vitruvius, it is clear that his countrymen were not acquainted with it.

The origin of the chain pump is due to a people as distinguished for their ingenuity and the originality of their inventions, as for their antiquity and the peculiarity of their customs; viz—the *Chinese.* This machine has been used in China from time immemorial, and as connected with their agriculture, has undergone no change whatever. The general form of chain pumps in China is that of a square tube or trunk made of plank; and of various dimensions according to the power employed to work them. A small wheel or roller is attached to each end of the trunk, over which an endless chain is passed. Pallets, or square pieces of plank, fitted so as to fill the bore of the tube are secured to the chain. When the machine is to be used, one end of the trunk is placed in the water, and the other rests on the bank over which it is to be raised. The upper wheel or roller is put in motion by a crank applied to its axle, and the pallets as they ascend the trunk push the water that enters it before them till it is discharged above.

In the latter part of the 17th century, chain pumps were used in British men-of-war but they were very imperfect. This at length excited the attention of European mechanics, and in the following century, numerous projects were brought forward to improve the chain pump or to supersede it. In 1760, Mr. Abbot invented a ship pump which was represented as of a very simple construction and which threw "five hundred hogsheads of water in a minute; (!) the handle turns with the utmost facility either to the right or the left. In 1761 the States of Holland granted to M. Liniere, "an exclusive privilege for twenty-five years, for a pump, which upon trial on board a Dutch man-of-war and in the presence of the Commissioners of the Admiralty being worked by three men, raised from a depth of twenty-two feet four tons of water in a minute, that is, 240 tons of water per hour." In 1768 Mr. Cole introduced some considerable improvements in English ship pumps.

The first United States ship of war which had one was the *Boston,* built at Boston, in 1799. The chain was formed of common ox chains, and the wheel which carried it was of wood, having forked pieces of iron driven into its periphery, between which the

chain was received: the cylinders were common pump logs of six inches bore. This imperfect machine was replaced the following year by one formed after a French model, the chain and cylinders being of copper. In 1802, the *Frigate Constitution* had two similar ones placed on her, and about the same time they were adopted in other public vessels, but in the course of a few years were discontinued generally either from prejudice of the seamen or from the increased labor and expense of repairing the pistons. In ordinary pumps, a single box or piston only has to be re-leathered; but in the chain pump, from thirty to fifty have to be renewed when worn out. The chain pumps in the British sloop-of-war *Cyane* were taken out when she was captured and common pumps put in their place. However, a change of opinion respecting these pumps took place, for within a few years they were to a limited extent reintroduced into the Navy.

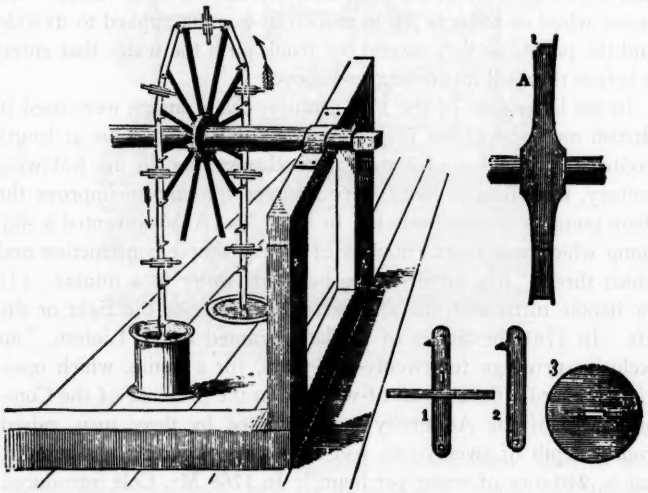

FIGURE 7.
CHAIN PUMP IN THE U. S. SHIP "INDEPENDENCE."

In 1837 the *Independence* was furnished with two of them; and in 1838 the same number were placed on the *Ohio*. Both vessels still retained their ordinary pumps.

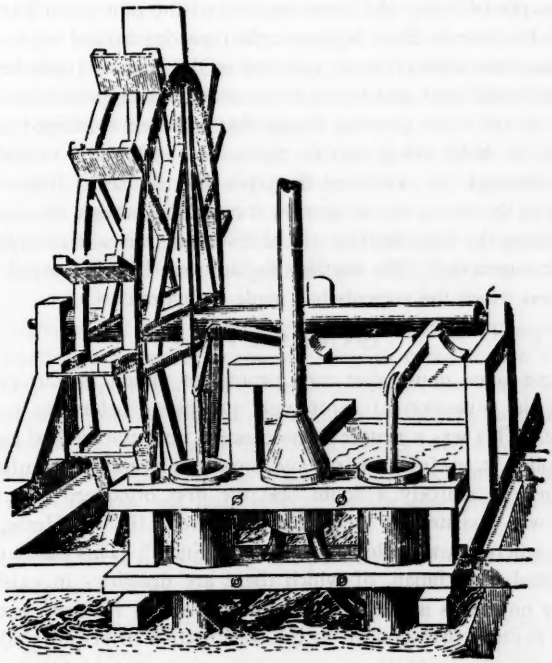

FIGURE 8.

MACHINE OF CTESIBIUS.

It remains now to describe the celebrated pump of Ctesibius, which according to Vitruvius is as follows:—

"This is made of brass; at the bottom a pair of buckets (cylinders) are placed at a little distance, having pipes like the shape of a fork annexed, meeting in a basin in the middle. At the upper holes of the pipes within the basin are made valves, hinged with very exact joints; which, stopping the holes, prevents the efflux of water that will be pressed into the basin by the air. Upon the basin a cover like an inverted funnel is fitted, which is adjoined and fastened to the basin by a collar, riveted through, that the pressure of the water may not force it off; and on the top of it, a pipe called the tuba, is affixed perpendicularly. The buckets (cylinders) have

valves placed below the lower mouths of the pipes, and fixed over holes that are in their bottoms; then pistons turned very smooth and anointed with oil being enclosed in the buckets (cylinders) are worked with bars and levers from above; the repeated motion of these up and down pressing the air that is therein contained with the water, the holes being shut by the valves, forces and extrudes the water through the mouths of the pipes into the basin; from whence rising to the cover, the air presses it upwards through the pipe; and thus from the low situation of the reservoir, raises it to supply the public fountains." The machine as thus described is a proof of the progress which the ancients had made on hydraulics.

CENTRIFUGAL PUMPS.

There is no doubt that each prominent nation in Europe considers the invention of centrifugal pumps as belonging to their people. This was a matter of no concern until the method came to be applied to useful purposes and took its place as a manufacture, but there is scarcely a doubt that the first organized centrifugal pump was invented by Denis Papin in about 1689 at Hesse, Germany, where it was called the " Hessian Suck." This pump of the celebrated Frenchman, of which there are drawings in existence, was by no means a bad one, and in all essential features, except a volute casing, corresponded to the construction afterwards adopted in this country in 1818.

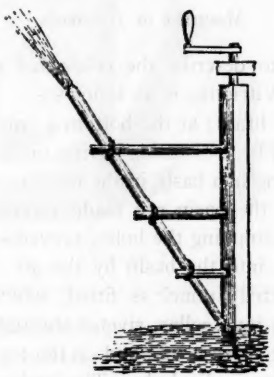

FIGURE 9.
LEDEMOUR'S PUMP.

Huet, the celebrated Dutch engineer, claims that Perreboom introduced the horizontal centrifugal pumps in Holland in the first years of the Nineteenth Century, but as no precise date or examples are named, some allowance can be made for Huet's evident prejudice against centrifugal pumping.

Another of the oldest drawings, extant at this time, is that of LeDemours, a Frenchman, dating from 1732. It was merely a straight tube attached in an inclined position to a vertical axis, and whirled round by the handle—the tube was fastened by ligatures to three strips of wood projecting from the axis and perpendicular to it.

To begin at the true beginning, when centrifugal pumps first took practical and useful form, we have to come to the United States. It will no doubt surprise most of us to know that centrifugal pumps as practical operative machines are strictly and entirely an *American Invention,* and that twenty years before such pumps were made or known in Europe they had in this country attained a form and efficiency but little inferior to the best practice of the present day.

A chronological list showing the milestones of early centrifugal pump progress follows:

The Massachusetts pump	1818.
Blake's pump	1831.
Andrews' pump	1839.
James Gwynne's pump	1844.
Bessemer's pump	1845.
Whitelaw's pump	1848.

A pump embodying almost every essential feature of modern practice was invented in Massachusetts in 1818, thirty years before the same thing was applied in Europe, and forty years before there was a modification that could be called an improvement. The impeller consisted of four straight vanes, each vane perpendicular to two other vanes and parallel to the remaining vane. This construction formed a small square at the center. The casing was of rectangular section, bevelled from the center to the periphery, but not in a degree to conform to volume and velocity as a theoretical pump of our day would be, but an approximation that showed the inventor had an inception of the true working conditions.

In 1839 Andrews invented or published the first American pump with a cylindrical discharge chamber. The Massachusetts pump came near anticipating our best modern practice and the Andrews pump completed the matter. The construction, in side view is identical with the Massachusetts pump invented in 1818, Andrews' invention relating to a cylindrical chamber at the vane tips. By 1846 Andrews had developed the encased or closed impeller and

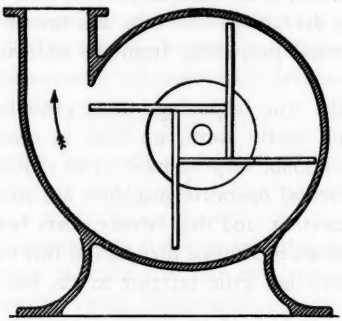

FIGURE 10.
THE MASSACHUSETTS PUMP.

after the pump had been applied to a great variety of purposes in this country it was improved and again patented both here and in England, Messrs. Gwynne & Co. acquiring the right for that country. It is interesting to note that the first centrifugal pump used in the United States Navy was in service at the Navy Yard, New York, in the year 1830.

ROTARY PUMPS.

We have little information on rotary pumps. Their exact origin is not known. The first rotary pump that we can trace is one found in a collection of models which belonged to Sérviere, a French gentleman, born at Lyons in 1593, although Ramelli is said to have described some similar ones in the middle of the 16th century.

The rotary pump found in the Sérviere collection consisted of two cog wheels, the teeth of which are fitted to work accurately into each other, are enclosed in an elliptical case. The sides of these

wheels turn close to those of the case so that water cannot enter between them. The axle of one of the wheels is continued through one side of the case, and the opening made tight by a stuffing box or collar of leather. A crank is applied to the end to turn it, and as one wheel revolves, it necessarily turns the other. The water that enters the lower part of the case is swept up the ends by each cog in rotation, and as it cannot return between the wheels in con-

FIGURE 11.
ROTARY PUMP FROM SÉRVIERE.

sequence of the cogs being there always in contact, it must necessarily rise in the ascending or forcing pipe. The machine is therefore, both a sucking and forcing one. Rotary pumps have never retained a permanent place among machines for handling water but have found their place in handling the more viscous fluids.

EARLY STEAM PROPULSION AND PUMPS USED.

Thomas Ewbank tells us that his investigation shows that Capt. Balasco De Garray, Spanish Navy, caused to be built and demonstrated in 1543, a ship of 200 tons propelled by steam. The trial of this vessel, the *La Trinidad,* took place on 17 June 1543 in the harbor of Barcelona, Spain. The machinery of this vessel apparently consisting of "a large copper for boiling water, a paddle-wheel on each side of the vessel and a steam engine" of a type not

disclosed. Report of the Royal Commission on the test of this vessel indicates that "the vessel tacked with the same rapidity as a galley, maneuvered in the usual way and went at least a league (3 knots) an hour."

However, the first record of the practical application of steam propulsion for a vessel credits William Symington with building the *Charlotte Dundas* in 1801 in Great Britain. This vessel worked with success for sometime as a tugboat on the Forth and Clyde Canal, but was withdrawn from this service on account of the destructive effects of the "wash of the propeller on the banks of the canal." This ship was fitted with a single paddle-wheel placed near the stern, driven by a horizontal direct acting engine with a connecting rod and crank. The first record of steam propulsion proving a commercial success credits Robert Fulton with building the *Clermont* in 1807. Credit for the second commercially successful steam propelled vessel and the first steam propelled passenger vessel in Europe goes to Henry Bell, who in 1812 built the *Comet,* which plied the Clyde in Great Britain between Glasgow and Greenock. This vessel was propelled by paddle wheels, driven by an engine of a design closely approaching what later was known as a "side lever engine."

History tells us that in 1814 the *Demologas,* later renamed the *Fulton,* was built at New York. This vessel was of 2475 tons displacement, was in reality the first steam propelled vessel of war of which we find a record. The first steam propelled U. S. war vessel which was built as such and which saw active service with our Navy was the *Fulton 2nd,* a vessel of 1260 tons displacement, driven by a 2-cylinder horizontal jet condensing engine 50-inch diameter cylinders, 9-foot stroke and developing 625 H.P. at 20 R.P.M. The first U. S. S. *Mississippi,* built in 1839 at Philadelphia, was fitted with a 2-cylinder side lever engine, 75-inch diameter, 7-foot stroke. Records show that steam propulsion for war vessels was first introduced in the British Navy in a small vessel of 210 tons known as the *Monkey,* built in 1820. This vessel was powered by a Boulton and Watt engine of 80 H.P. consisting of 2 cylinders 35½ diameter by 3 feet 6 inches stroke turning at 26½ R.P.M. This vessel was followed in 1822 by the *Active* of 80 H.P. and in 1823 by the *Lightning* of 100 H.P. Between

1823 and 1840 seventy other steam propelled vessels were added to the British Navy, the majority of which were fitted with side lever engines which worked with steam at about 4 pounds gauge pressure. The U. S. S. *Mississippi*, built in 1839 in Philadelphia Navy Yard for the U. S. Navy, was also fitted with a side lever engine.

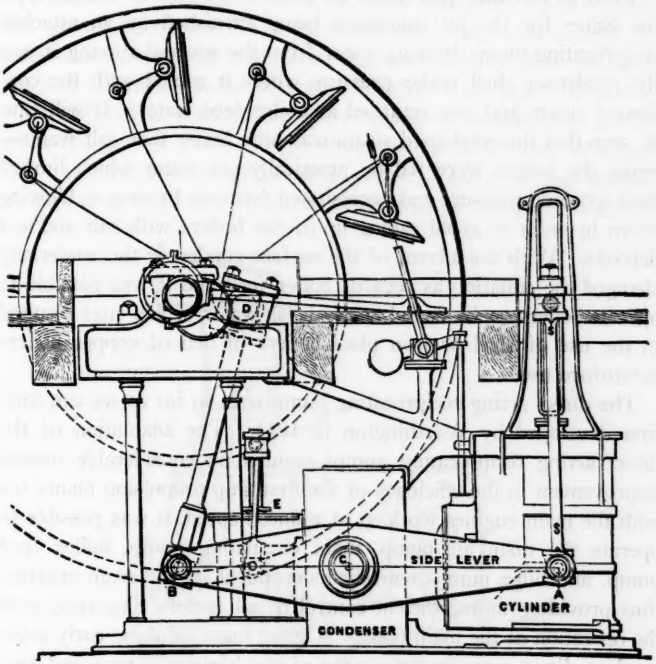

FIGURE 12.
SIDE LEVER ENGINE.

It is on such a side lever engine that we find the first record of the application of reciprocating pump applied to marine propulsion. In this case the main condenser air pump is connected through a cross-head and connecting rod to the side lever or beam of the main engine. From this time on, 1839-1840, the application of the reciprocating pumps, both horizontal and vertical, connected to and driven by main engines became of almost universal application

in the U. S. and Great Britain for main air pump service, boiler feed pump service, bilge service and in some cases main condenser circulating pump service. The application of surface condensers to marine propulsion about 1846 resulted in a big step ahead for ship-board installations of steam engines.

Prior to this time practically all condensers were of the jet type, the water for the jet condenser being furnished by an attached reciprocating pump drawing water from the sea and forcing it into the condenser shell under pressure where it mixed with the condensed steam and was returned as boiler feed water. It will thus be seen that the condensed steam was little better than salt water—hence the boilers were fed on practically sea water which limited their working pressure and necessitated frequent brining or blowing down in order to avoid caking up of the boilers with salt and salt deposits. With the advent of the surface condenser this materially changed the situation as regards boiler feed and it was possible to operate boilers on fresh and nearly fresh water, which later resulted in the use of steel or iron plate boilers in lieu of copper boilers heretofore used.

The direct acting reciprocating pump was, so far as we can find, first developed by Worthington in 1844. The adaptation of the direct acting reciprocating pumps resulted in considerable overall improvement in the efficiency of the first ship propulsion plants for with the main engines working at reduced speed, it was possible to operate the main air pump, main circulating pump, boiler feed pump, and bilge pumps entirely independent of the main engines, thus providing more efficient control of all factors concerned with the operation of the main plant. A great many of these early independent direct acting pumps were of the horizontal type and frequently they were of the outside packed plunger type single acting, although many were of the direct double acting type with inside packed pistons. In 1850 we see our first separate steam driven pump, a fire and bilge pump, placed aboard the U. S. S. *Powhatan*. The first independent air pump was installed on the *Wyandotte* (monitor class) and consisted of a single vertical steam cylinder actuating two beams, the one carrying two vertical single acting air pumps and the other two vertical circulating pumps. In 1883 construction was started on the U. S. S. *Dolphin*. It is of particu-

lar interest to note that this was the first Naval vessel in which no pumps were worked from the main engines.

With the increase in size, power, number, and complications of pumps and pump installations aboard Naval vessels, it soon became apparent that deck space for installation of horizontal pumps was at a premium. It should be borne in mind that after all the supply and acceptance by the Navy of horizontal pumps was simply the acceptance of what the pump manufacturers had to offer and what had been furnished to the Merchant Marine in the past. However, when with Naval vessels deck space became a premium, the use of horizontal pumps was no longer practical due to the lack of space. This required the development of vertical direct acting pumps, which was met by the various manufacturers as demand warranted.

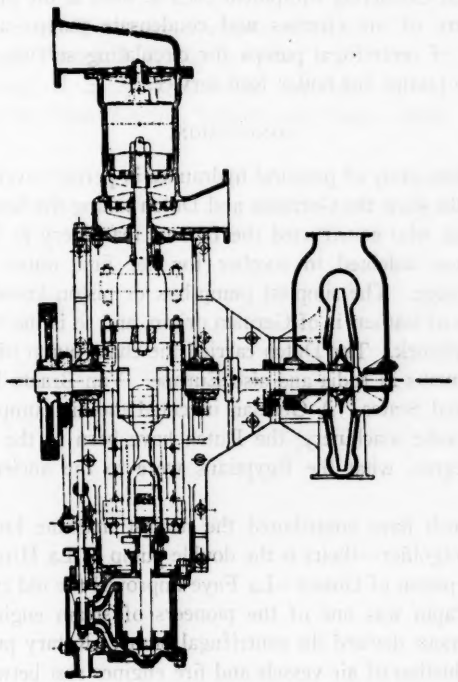

FIGURE 13.

COMBINED DYNAMO OR AUXILIARY AIR AND CIRCULATING PUMP.

It will thus be seen that the first step toward the present ever pressing requirement for further reduction in weight and space occupied by auxiliary machinery was initiated at a very early date. This attempt to meet requirements for reduced space limitations was further met by combining the air pump and the circulating pump in one unit, such as is illustrated in Figure 13.

This combination of a number of units with a single driving unit has been carried through in our Navy even in as recent as 1925 to 1930. With the increase in power of our main engines it soon became apparent that even with the best possible design of reciprocating pumps the space occupied by main air pumps and main circulating pumps was out of all proportion to their accomplished results. This led to the development or the adaptation of various modified forms of air extracting equipment such as used at the present time in the form of air ejectors and condensate pumps and to the adaptation of centrifugal pumps for circulating service, and later, multi-stage pumps for boiler feed service.

CONCLUSION.

A complete study of practical hydraulics in period covered by this article would show the Germans and Dutch taking the lead. It was a Dutchman who constructed the famous machinery at Marli and England was indebted to another for her first water works at London Bridge. The simplest pump-box or piston known, the inverted cone of leather, is of German origin, and so is the tube pump of Muschenbroek. The Dutch carried the chain pump of China to their settlements in India and also Europe. Van Braam brought it to the United States. A German invented the air pump. As regards hydraulic machinery, the Dutch have been to the moderns, in some degree, what the Egyptians were to the ancients—their teachers.

The French have contributed the neatest machine known; the ram of Montgolfier—theirs is the double pump of La Hire, and the frictionless piston of Gosset—La Faye improved the old tympanum of Asia—Papin was one of the pioneers of steam engine design and Le Demour devised the centrifugal pump. Rotary pumps and the reintroduction of air vessels and fire engines rest between Ger-

many and France. The English revised the plunger pump and stuffing box of Moreland and furnished the expanding metallic pistons of Cartwright and Barton—the steam engines of Worcester and Savery, Neucomen and Watt and the quicksilver pump of Hawkins. Switzerland contributed the spiral pump of Wirtz. The United States contributed the Massachusetts centrifugal pump and the Worthington independent direct acting reciprocating pump.

Few classes have a more honorable career before them than intelligent mechanics. Certainly none have better opportunities of associating their names with those of the best of their species. Science and the arts open the paths of glory; and greater triumphs remain to be achieved in both than the world has yet witnessed.

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THE PRESENT TREND IN MARINE ENGINEERING IN THE UNITED STATES OF AMERICA.

The following abstract is from a paper presented before the International Conference of Naval Architects and Marine Engineers in London, England, during June, 1938, by Mr. John E. Burkhart, the Chief Engineer of the Bethlehem Shipbuilding Corporation, Quincy, Mass. While the paper deals only with merchant marine machinery, it cannot but be of interest to all naval engineers in this country who know Mr. Burkhart, and are aware of the influence which his opinions have exerted in affecting the trend of which he speaks. Only an appendix dealing exclusively with the various types of feed systems now under discussion has been omitted.

This paper deals exclusively with the machinery of ocean-going merchant vessels. Naval vessels and those plying the Great Lakes and inland waters of the United States are for special service and are beyond the scope of this paper.

For many years marine engineering in the United States followed rather closely that of Europe. In the last generation there have been departures due not only to the natural result of independent thought and action but also in response to differences in practical and economic conditions.

Perhaps the most important of these is the cost of labor. Engineering economy rests upon a balance between first cost and maintenance on the one hand, and fuel savings on the other. Labor is a large factor in first cost and maintenance. In the United States labor costs are very much higher than in Europe, while fuel savings are about the same. What would be a fair return on investment abroad may fail to be attractive to the American business man who is in the habit of expecting a somewhat larger return on invested capital than is customary in Europe. Under these circumstances the Diesel engine, when it involves greater cost, and a number of devices such as the exhaust turbine as an adjunct to the steam reciprocating engine, have been unable to make the same progress as in other countries.

Another difference lies in the type of operating personnel. These are generally strictly operating engineers trained as such, as distinct from shop mechanics. Voyage repairs and maintenance are now customarily done by an independent crew. The stay in port is short and machinery that frequently requires maintenance or minor adjustment is no longer popular.

Quality and cost of available fuel are other factors of importance. The labor of handling and general inconvenience have largely eliminated coal except in the coal-carrying trades. There is a tendency towards the use of heavier high viscosity residues for burning under boilers. Many of our tankers are burning fuel which has a specific gravity greater than unity and requires special provisions for pumping and heating.

All of these considerations: high labor cost, type of operating personnel, and available fuels, inevitably affect first cost, maintenance, and fuel economy, and therefore the trend of all marine engineering development. They are the reasons why Diesel propulsion has not advanced in the United States as it has abroad except for vessels of small power.

Figure 1 shows the approximate fuel consumption of various types of drive, and the influence of size of installation on this consumption. The advantage of the Diesel drive is about 30 per cent at high powers, increasing with the smaller installations.

On the other hand, Figure 2 shows how cost varies with size of installation. At low powers the advantage lies with the Diesel, but it loses this rapidly as powers increase.

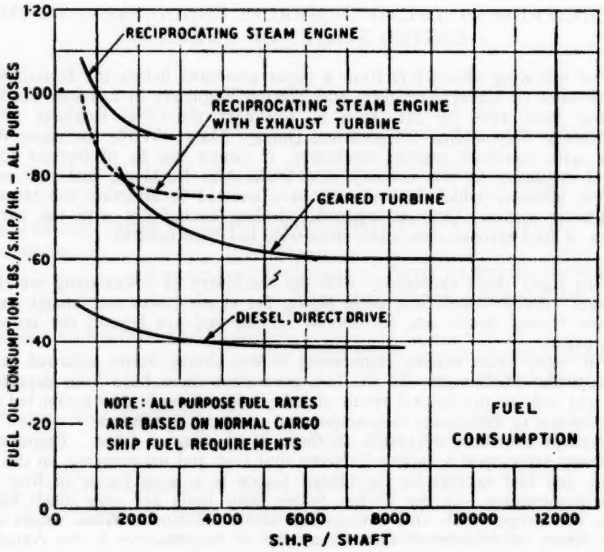

FIGURE 1.

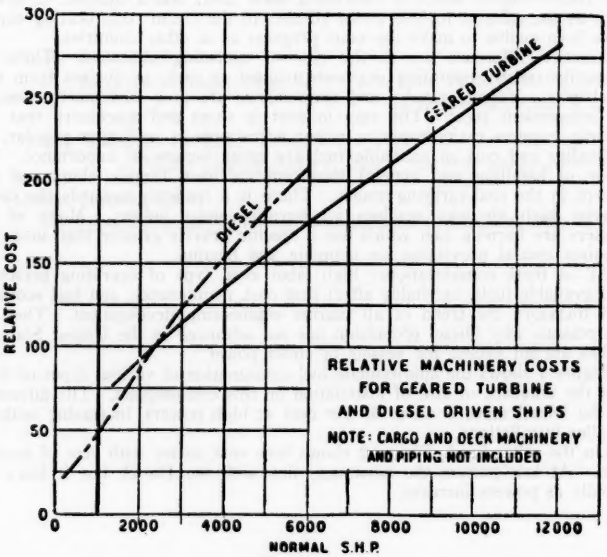

FIGURE 2.

Cost of fuel has a direct bearing on the economic value of the efficiency of the machinery. Figure 1 shows that the fuel consumed by a Diesel installation is only two-thirds that of the geared steam turbine, and less at small powers. This could be a very great advantage if the prices of Diesel and bunker oil were the same. While oil prices vary in the markets of the world, the American owner is usually most interested in the price in United States ports because a majority of United States shipping is engaged in coastwise trade or bunkers at United States ports. In April, 1938, the average price of Diesel and bunker C fuel oils for a number of United States seaports was $2.20 and $1.35 per barrel, respectively, and this ratio is typical over a long period. It is enough to wipe out the large gain of the Diesel engine except for low-power installations. In such installations, say up to 1500 H.P. per shaft, the Diesel engine has almost completely displaced steam. In this field it costs less and uses much less fuel, sufficient to offset the higher price of the Diesel oil.

The Diesel engine has some friends among owners of larger vessels, and there are conditions in the service of any specific vessel that have to be taken into consideration in deciding upon the type of machinery, e.g., a long voyage between fueling ports and a deadweight cargo. In such a case the great reduction in weight of fuel carried by the Diesel increases the earning capacity by just that much, and may be an important consideration.

However, the fact remains that although a few larger power Diesel installations have been made, the result on the whole has been to confine Diesel propulsion to the smaller powers, while steam generally has held the field in larger vessels.

Between 1500 and 2500 S.H.P. per shaft constitutes a more or less neutral zone in the foregoing considerations. In this range the decision between Diesel and steam might well be governed by other and secondary considerations. It so happens that there is practically no demand for installations of this size at present, and little is indicated for the future.

The present demand is for 4000 to 8000 S.H.P. per shaft. What is the probable line of development of the Diesel in order to compete in this field? Its advantage in quantity of fuel consumed is important, but is unfortunately largely offset by the difference in price. A satisfactory practical solution to the difficult problem of utilizing heavy bunker oils in the Diesel engine would at once put it into a competitive position, but this appears still far in the future, if indeed it will ever be achieved. The possibility of reducing first cost does not appear so remote.

Experience has shown that our high labor costs in America can be offset by multiple production methods where the quantities will permit. It seems not unlikely that the quantity production of the smaller Diesel engines in other fields might so reduce the cost as to make this type of prime mover attractive in a wider marine field.

There has been a very large development of Diesel engines in these smaller powers outside of the marine field, and that development will undoubtedly continue in the future. The most recent of these is for locomotives. These engines are about 1200 S.H.P. run at 750 R.P.M.

Marine engineers could adapt these smaller engines to marine requirements. Such engines will be of relatively high rotative speed, and require some form of reducing transmission to suit the propeller revolutions which are tending lower rather than higher. Gearing or electrical transmission is available for this purpose. The first installation of geared Diesels in the United States was made about nine years ago. It consisted of two 1300-H.P. eight-cylinder four-cycle engines running at 275 R.P.M., driving the propeller shaft at 90 R.P.M. The reduction gearing was of the regular marine type, except for the lubrication. The bearings took oil from the lubrication

system of the main engines, but the gear teeth were lubricated by dipping in a bath of heavy compound without any provision for cooling. Simple spring couplings of the Falk-Bibby type fitted between the crankshaft and pinion constituted the only provision for flexibility. This unit has operated entirely satisfactorily.

Except as to cost, the electrical method has much in its favor. About 150 Diesel electric drives for smaller powers, aggregating 117,000 S.H.P., have been installed in the United States, and while their first cost was rather high, they have been very successful.

The transformation of mechanical to electrical energy and back to mechanical energy does not at first appear attractive either for economy or first cost, but there are compensations. The engine needs no reversing gear, air compressors and air storage are much reduced, and the increasing use of electrical equipment throughout the ship fits well with the general requirements of certain classes of ships.

It would seem, therefore, that if the Diesel engine is to take a larger proportionate place in the propulsion of American ships than it has in the past, development may very well be along the lines of smaller high-speed standard main units, the power being transmitted to the propeller either electrically or by gearing; the former where the ship's electrical load is rather high, and the latter in other cases.

The author does not necessarily advocate the foregoing as the ideal marine drive. It is outlined as a probable line of development of the Diesel engine in the United States for the reasons given.

Propeller revolutions are an important factor in any installation. Lower revolutions usually mean better propulsive efficiency. In the past some sacrifice in efficiency has usually been made in order to favor the main engines, to keep the propeller diameter within practical limits, or simply to reduce weight. The modern trend is toward the curtailment of these sacrifices. There is perhaps no place left in a marine installation where a little further economy can be picked up at so little cost and engineering risk. Except in the slower types of ships revolutions have been reduced about 20 per cent.

In the author's opinion this reduction of revolutions is being overdone in a number of cases. The optimum of efficiency can only be realized when it is practicable to swing a propeller large enough to get the full advantage of the lower revolutions, and this is not always the case.

To maintain the higher propulsive efficiencies now almost universally obtained, built-up propellers with separately bolted blades have been replaced by solid propellers for all classes of ships, and aerofoil blade sections have become the rule.

For steam-driven main propulsion machinery, pressures of 400 to 450 pounds per square inch and temperatures of 700 to 750 degrees F. have become standard over a wide range of powers.

The use of higher pressures of about 600 pounds has been considered in combination with the same temperatures, but so far has not been adopted in an actual installation.

There would be a small gain in thermodynamic efficiency. There is also reason to believe that, due to the decreased volume of steam liberated for a given output, the boilers steam more easily. If this could be evaluated and the advantage realized, it might be one of the principal gains. The steam piping is smaller in diameter, which is helpful in providing for expansion.

The disadvantages of higher pressures are that heavier scantlings are required in the main steam lines from the boiler drums to the H.P. turbine inclusive, and there is more engineering risk in the joints, etc. The feed-system is similarly affected, and the power required for the feed-pump is increased. Parasitic losses in the main turbines, particularly in the H.P.

turbine, rapidly increase with pressure. Unless the turbine is of fairly large power these disadvantages are rather important; at 4000 to 6000 S.H.P. they more than offset the thermodynamic gain.

The foregoing considerations lead to the conclusion that there is nothing to be gained by going to 600 pounds pressure except for high-power installations. Even at 20,000 S.H.P. the improvement in fuel economy would be only of the order of 2 per cent. There is much more to be gained by increase in superheat. This development still awaits confidence in materials.

While mild steel has been satisfactory up to 750 degrees F., various alloys having superior resistance to heat and creep are being adopted, notably at strategic points like superheater tubes. Also molybdenum alloys are being adopted rather extensively, and will probably replace mild steel for everything in contact with superheated steam.

The greatest threat to adequate reliability by further increase in temperature probably lies in the life of the superheater tubes and secondary effects of a more practical nature like expansion, joints, etc.

BOILERS.

The design of boilers at present appears to be in a state of flux.

The Scotch boiler is practically obsolete for new construction even for moderate pressures.

The Babcock & Wilcox header type boiler has been used for many years, and on account of its large background of good experience is still preferred by many owners.

The three-drum type exemplified by Yarrow, although used almost exclusively and developed to a high degree in naval vessels, has not found its way into the American merchant service until comparatively recently, notwithstanding that it has proved itself to be very rugged and capable of heavy overloads. The present trend seems to be toward this type of boiler in some form, having an upper steam drum, one or two lower waterdrums, and a nest of small tubes between, arranged preferably for a single flow of gas, as this simplifies the superheater, air-heaters, and economizers.

Except in special cases, oil is used almost exclusively for fuel. Several pulverized coal installations were made a few years ago, but they have had no influence on marine practice, although the trend in large land power-station practice is definitely toward powdered coal.

Oil fuels used are often high viscosity residues, sometimes with a specific gravity greater than unity, requiring rather special provisions for pumping and heating.

The trend is definitely toward fewer boilers and larger units. Two-boiler installations are becoming common up to 6000 H.P., and will undoubtedly be used for higher powers.

Ratings are still conservative. In general, no attempt is being made to take up the known margins in capacity. At maximum power the pounds of oil burned per square foot of total surface, i.e., generator, superheater, and economizer, is about 0.3. The oil burned per square foot of radiant surface does not usually exceed 16 pounds, and the heat release per cubic foot of combustion space is usually not over 70,000 B.T.U. per hour.

Efficiencies of 87 per cent are expected and usually obtained.

To obtain this efficiency extended surface either in the form of air heaters or economizers is necessary to bring the uptake gases down to about 300 degrees F. Air-heaters have a large background of good experience. Economizers have been used in the last few years in quite a number of ships, and appear to be popular with some of the owners at the moment.

A proper installation of air-heater occupies more space than economizers, and when space is limited the economizer might well be the best means to obtain the required heat extraction. On most ships, however, there is usually space enough for air-heaters.

Air heaters when installed with tubes more or less vertical with the gases inside and air outside are practically self-cleaning. Such installations, similar in principle to those used on a Scotch boiler with Howden's forced draught, have demonstrated their practical effectiveness over many years. However, there have been a few recent cases of air-heaters that have given trouble. These have horizontal tubes with the gases on the outside. Carbon deposit was allowed to accumulate in the corners of the tube nest culminating in a fire which burned out the tubes. In the author's opinion these failures are not chargeable to the principle of air-heating, but rather to the method by which it was carried out in these particular cases. They have, however, undoubtedly had the effect of turning some owners from air-heaters to economizers.

Economizers are essentially an extension of the pressure parts of the boiler, practically as vulnerable, and require equal or more maintenance. Although plain tubes may be used for economizers, the preferred type have circumferential gills on the outside. For heat transference the external gills appear logical as they provide about five times as much surface in contact with the gas as is provided by the smooth bore in contact with the water, thus more nearly approaching the ratio of the respective resistances of the water and gas surfaces. The fins also make it possible to carry higher water velocities in the tube, which is considered desirable to keep the interior swept of liberated air. From a practical standpoint, however, there is the problem of keeping the outside of the tubes clean. This will always be much easier with plain tubes.

Forced draught is the rule, and air pressures are increasing to take care of the increased resistance due to the extended surfaces, with the result that slight air pressures in the furnaces are not uncommon. Induced draught has been used with success, but it would appear that this system is not likely to be extended. It becomes increasingly difficult to apply as the amount of draught increases. Up to the present, combined or balanced draught, i.e., both forced and induced in the same installation, has not found much favor.

Riveted drums are rapidly becoming obsolete, and while forged drums were used for a few installations, welded drums are now the practice.

Desuperheaters, consisting of a simple coil in the steam drum, are practically always used for the supply of auxiliary steam. The tendency is towards smaller desuperheaters so as to leave somewhat more superheat in the auxiliary steam. Fifty degrees or more of superheat is found to reduce corrosion and erosion in auxiliary turbines.

Automatic feed regulators, soot blowers, and smoke indicators are usually installed. The last-named are fitted to each boiler. By lenses and mirrors their indications are carried down to a convenient place on the firing floor. They have been found to be very effective in eliminating smoke nuisance, and generally regulating combustion, especially during the variations in steam demand incident to maneuvering in and around port.

A number of ships have been fitted with automatic combustion control, and the vogue for this appears to be increasing.

The details of the application vary. A typical installation is as follows: Fans and fuel oil pumps are driven by variable-speed motors. The fan motor rheostat is operated through a pneumatic relay, by the variation in steam pressure, so that rising pressure slows the fan and *vice versa*. Simultaneously another relay, also actuated by steam pressure, varies the fuel oil

pressure at the burners by the throttling action of a regulating valve in the line supplying the burners.

To maintain constant CO_2 another relay, actuated by the gas-pressure drop through the boiler and by the pressure drop through an orifice in the fuel oil supply pipe, effects a final adjustment of the oil flow.

The system requires a number of sensitive devices and entails appreciable complication. As the available burners have a narrow effective range (say, 30 per cent), the automatic operation must be supplemented by manual shifting of the number of burners and size of tips when large changes in power are required.

Experience with this type of equipment is not yet entirely satisfactory, and probably will not be until we have a burner of wide effective range and large capacity so that only one is required on each boiler.

There has arisen a demand for boilers designed to provide for control of the amount of superheat. Boilers having this feature are now under construction for two tankers. Two or three designs have been offered, all having two furnaces, the gases from one only passing over the superheater. Manual regulation of the amount of oil supplied to each furnace gives the superheat desired. During maneuvering and astern operation the superheat can be reduced or almost entirely eliminated.

In the early days of the use of superheat, when the factors affecting, and affected by, superheat were not so well known as they are now, such a scheme for the control of superheat would have been welcomed. Those early difficulties have now been overcome, and there seems to be no reason to depart from the present simpler arrangements.

However, if it is desired to attempt operation at temperatures appreciably higher than the present practice (700-750 degrees F.), superheat control would be of real advantage not only in regulating the temperature in a range where lack of experience makes matters uncertain, but it would afford the privilege of reducing the temperature for an indefinite period in case of trouble without any appreciable sacrifice in power or speed. On the other hand, there is the complication that the operators must fire the boiler for temperature as well as pressure, and since mistakes might be serious, reliable automatic devices and alarms will be necessary.

American marine engineers are interested in the development of forced circulation for boilers, but they believe that such radical innovations should be developed to the point of reliability on shore before attempting their adoption on board ship.

The high efficiency of the present boilers with natural circulation leaves little scope for improvement in that direction. Presumably weight and space will be reduced and there is the probable advantage of being able to design the boiler without regard to shape limitations imposed by natural circulation.

One design that appears to have promise is based upon a limited amount of circulation, about 20 per cent of the total feed instead of ten times or so proposed in other designs. If this small quantity proves sufficient to prevent the precipitation of solids in the tubes, and the circulation is enough to ensure satisfactory distribution in the various circuits, there is much to be gained, since no separate circulating pump is required. A few small units have been built along these lines for land service, and experience with them is being watched with interest.

MAIN ENGINES.

For the steam-driven main-propelling units the geared turbine predominates.

Reciprocating steam engines of modern type with poppet valves and exhaust turbines might have been used in lower power installations, of, say, 1000 to

2500 H.P., but there has been such small demand for installations of these powers that little or no development has taken place along these lines.

At about 3000 H.P. and above, these engines cannot compete with the geared turbine either in first cost or fuel economy.

So-called modernization of the older reciprocating engines by the addition of superheat, exhaust turbines, poppet valves on H.P. cylinders, and other similar devices has not taken hold in the United States in spite of the large fuel savings that result therefrom. These are not large enough to amortize the cost of conversion in less than ten or twelve years, so the arrangement is not attractive to the average American owner.

Turbo-electric drive had most of its early development in the United States. Up to the present, 56 American-built merchant vessels have been so fitted with a total of 340,000 S.H.P. So far as the author knows, all these installations have operated satisfactorily. However, the electric drive is not holding its own against the geared turbine because it costs more and is slightly less efficient. Weight and space required are also greater than with the geared turbine.

Turbo-electric drive has undoubtedly been adopted in many cases for reasons other than engineering economy. Experience has served to demonstrate its practical effectiveness in service. It will take its proper place in the scheme of things, for it has advantages of value in special types of vessel, notably those in which: (*a*) There is a large demand for electric power other than for propulsion; (*b*) Quick maneuvering and large astern power are unusually important; (*c*) It is necessary to arrange the machinery in the vessel without restrictions due to lengths of shafting, steam piping, etc.

Both impulse and combined impulse-reaction turbines are used about equally for marine propulsion in the United States, but no all-reaction turbines have been built in recent years. The blade elements usually consist of a two-row Curtis wheel, followed by about fifteen Rateau stages in the impulse turbines. There are about forty-two reaction stages in the impulse-reaction turbines. In all cases the Curtis, or first stage, takes a comparatively large pressure drop, absorbing 20 to 25 per cent of the total heat available in the steam.

The Curtis first stage has been used in the United States for many years. It leads to a shorter and more rugged unit without appreciable loss in efficiency; in fact, for small powers there is a slight gain. In modern turbines there is the advantage that the work done by the steam at the highest pressure and temperature is confined to a relatively small portion of the turbine.

Blade speeds, measured at the middle of the longest blade, run about 700 feet per second for impulse, and about 550 for reaction turbines. These blade velocities, in combination with the Curtis wheel for the first stage, permit the extraction of the available energy in the steam to be accomplished efficiently by two turbines in series.

For powers up to about 10,000 S.H.P. per shaft two turbine arrangements have superseded three turbines, not only because of its general simplicity, but also due to better efficiency, especially at the lower powers. The parasitic losses are generally reduced. Gland leakage and bearing losses are proportional to the number of cylinders. Dummy and tip leakage losses in reaction turbines and rotation and bushing losses in impulse turbines are reduced because the H.P. turbines, running at high speed, are of smaller diameter. The reaction H.P. turbines run at about 5500 R.P.M., and the impulse at about 6500. Such speeds, of course, require double reduction gears.

At powers above about 10,000 S.H.P. per shaft three turbines in series would probably show a better efficiency and tend toward a better arrangement when the effect on the gears is taken into consideration.

The high-pressure turbines are small in size and of rugged appearance. The reaction turbine rotors are usually only about 1 foot in diameter, and

the bladed part is less than 3 feet long. They are particularly well suited for operation with high-temperature steam because they are small and less likely to distort. The casings are cast steel, and the rotors are usually made from single forgings.

The nozzles of the Curtis wheel are divided in groups, each with individual control valves, making it possible to utilize practically full-pressure head at reduced powers to maintain efficiency under these conditions and avoid excessive throttling at reduced powers.

The low-pressure turbines are single flow up to about 8000 S.H.P. More care has been taken to keep the steam path smooth to avoid eddies.

While low-pressure rotors are generally made from single forgings, there are many of built-up design. One of these consists of solid discs bolted together with axial bolts at about half radius. Stresses are based more conservatively than formerly. The factor of safety in the rotor and blading based on the yield-point is never less than four.

The ratio of the last moving blade height to its mean diameter is usually not over one-fifth. With this ratio and with moderate blade speeds a simple parallel blade can be used. When the ratio materially exceeds one-fifth, the blade angle should vary radially to give good efficiency, and the blade assumes a warped shape. Such blades are usually tapered radially to keep the same centrifugal stress at the root. The resulting blade is complicated to machine, or must be drop forged. When repairs are urgently needed it is often an unfortunate handicap that nobody but the original manufacturer can undertake the job, while almost any turbine builder or turbine repair plant can produce the parallel blade. A similar handicap arises from the use of very high-blade speeds which also require tapered and warped blades.

Some low-pressure turbine casings are of cast iron of conventional design, but there is a tendency toward cast steel. In a number of installations the low-pressure turbine casing is a welded structure consisting of an outer sheet steel exhaust hood welded to an inner cast-steel cylinder carrying the blading. The sides of the exhaust hood in the lower half of the casing become heavy fore and aft beams whose after-ends rest on the gear casing and whose forward ends rest on the turbine foundations. The condenser is hung from these beams with no bottom supports. Another variant of this scheme is to build the fore end and aft beams into the top of the condenser and let the turbines rest on the condenser.

All turbines are under the control of a speed limiting and low oil-pressure governor, and some have an overspeed trip in addition. A guardian valve is often fitted between the astern throttle and turbine to prevent leakage into the astern turbine when running ahead. Labyrinth, carbon, and combined labyrinth and carbon gland packings are in use. To prevent gland steam leaking into the engine room, gland exhauster systems are sometimes fitted. They consist of a small fan or ejector drawing air and vapor from the external pocket of the glands and discharging to a small condenser. The tilting pad type of thrust bearing, as developed by Michell and Kingsbury, is used in most turbines, but one manufacturer uses fixed pads. These are machined to give a wedge-shaped oil film similar to that produced by the tilting pads.

The astern turbine generally consists of two impulse wheels at the exhaust end of the low-pressure turbine casing. In the high blade speed impulse turbines it usually consists of a two-row Curtis stage followed by a Rateau stage. In the moderate speed reaction turbines there is a two or three-row Curtis stage followed by a two-row stage.

Astern turbine elements incorporated in both high and low-pressure casings are not in favor.

All of these astern turbine arrangements have ample torque and power to stop the ship and maneuver it satisfactorily. Tests show that they have more stopping power than can be effectively utilized by the propeller. Very little is to be gained by increasing the torque beyond about three-quarters of the full-ahead torque, which represents current practice.

After attaining full sternway on the ship the astern power is about 55 per cent of the full-ahead power. This can be developed continuously, and is a fair measure of the capabilities of the astern turbine. In an attempt to specify conditions more nearly representative of stopping conditions it has been customary for owners to require 80 per cent of full-ahead torque at 50 per cent of full-ahead revolutions. This is not a satisfactory basis for a specification of an astern turbine, because it cannot be demonstrated on a trial. That particular combination of torque and revolutions occurs only momentarily during stopping, if at all, and therefore cannot be measured.

In the past there has been much discussion on the relative merits of single and double reduction gears. To advocate either indiscriminately is unsound. There is a field for both.

In the early days of double reduction gears in Europe there were troubles probably due to the details of application, but for which the principle was blamed, and subsequent development was temporarily arrested. American practice did not have this experience; double reduction gears have proved as reliable as single reduction, and there is no objection to them except the additional mechanical complication which, of course, should be avoided unless there are compensating advantages.

Accordingly, the revolutions of the turbines and propellers can be selected for the best efficiency of each. It is the function of the gearing to bridge the gap between them in the simplest way.

As already explained, the turbine revolutions have been tending higher and the propeller revolutions lower. This increase in the reduction ratio has extended the application of double reduction gearing to vessels of 16 and 18 knots, where it is now commonly used.

Consideration of turbine design usually results in much higher revolutions for the H.P. turbine than for the L.P.; sometimes nearly double. For vessels of higher powers and speeds it will be advantageous in some cases to use double reduction for the H.P. turbines and single for the L.P., and there seems to be no reason why this should not be done. Similarly, in a three-turbine series arrangement it will probably be best to use double reduction for the H.P. and single for the I.P. and L.P. turbines.

Tooth bearing pressures vary from 50 to 65 pounds per inch of face per inch of diameter. Some gear manufacturers would agree to higher loading, but most owners insist on conservative loading.

Peripheral speeds, limited to about 150 feet per second for many years, have been allowed to run up, following turbine revolutions. Speeds of 250 feet per second have been used successfully.

With the standards of accuracy of gear-cutting now prevalent, limitation of peripheral speed does not appear to be so important as formerly. The hydrodynamic theory of lubrication as applied to gear teeth indicates that higher peripheral speeds would permit of higher tooth loadings. Experience seems to bear this out. On the whole there has been more trouble with low-speed gears than with high, both using the same loading.

The necessity for limiting the torsional and flexural deflections of pinions is now well recognized and controlled by the ratio of length to diameter in relation to the loading.

In general, three bearing pinions with a center bearing between the helices are avoided where possible because of the difficulty of providing rigid sup-

port for the center bearing except when the pinions lie in the horizontal center plane of the main gear.

Both nested and separate train types of gear are used with equal success. The nested type is more compact. The separate train takes a little more length, but is considered more conservative. It simplifies alignment problems.

Most gear manufacturers use the conventional design of gear wheel consisting of a forged steel rim shrunk on a cast-iron or cast-steel center. One, however, uses a cast-steel wheel with the teeth cut directly in the rim. The casting is made by special process, resulting in a rim of perfectly sound material of suitable quality.

A more recent design consists of a forged steel rim and shaft joined by steel plate discs welded to both.

Gear casings are either of cast iron or, more recently, a combination of welded steel and steel castings.

The main thrust bearing is invariably incorporated in the forward end of the gear casing.

ELECTRIC PLANT AND AUXILIARIES.

There has been a steady increase in the size and importance of the electrical installation. With the exception of feed pumps, practically all auxiliaries in continuous use are now motor driven. In addition, the use of electricity for so-called hotel services has been greatly extended through the need for increased ventilation, air conditioning, refrigeration, galleys, and electrical appliances.

The smallest plants (on tankers) now have two 125 Kw. generating sets. Of course, passenger vessels have much larger plants.

Practically all installations are 240 volts D.C.; some of the smaller ones are 120 volts.

Alternating current has been applied in isolated cases. The principal advantage is that nearly all the motors can be of the squirrel-cage type. These are far more rugged and trouble free than direct-current motors with their commutators.

Motor generators (A.C.-D.C.) are provided for the direct current required for certain minor services.

The advantage of alternating current is greater in the larger installations where the capacity of generator installed is so much greater than that of any single motor as to permit using across-the-line motor starters instead of the usual compensator. There are indications of greater application of alternating current in the future.

All main generators are driven by geared turbines. Diesel installations, where provided, have been of small capacity, and generally for emergency duty only.

In a few cases an auxiliary generator driven from the main reduction gear has been provided, in addition to the regular auxiliary sets. When at sea the current is taken from the generator attached to the main unit while one of the auxiliary sets is kept idling at speed ready for instant operation. The gain in economy might be anything up to about 4 per cent, depending upon the power of the vessel, the amount of current taken, and the efficiency of the auxiliary sets. For an electric load of 100 Kw. and a water rate of 17 pounds per Kw.-hour, in a 3500 S.H.P. installation the gain is only 1½ per cent, and hardly worth the cost and complication of the equipment and controls.

Turbo-generators are usually multi-stage, high speed, condensing, designed for high economy. They operate at the same steam conditions as the propulsion unit, and the best water rates are roughly one-third higher.

In some low-capacity installations a non-condensing generator has been provided for heat balance, but the gain is doubtful.

Direct-acting steam pumps are not now generally used except for emergency and stand-by duty; e.g., emergency feed pump, bilge pump, general service pump; occasionally for other duties. The tendency is toward their elimination to avoid contamination of feed by lubricating oil.

For all applications in continuous service rotary units are usual.

Feed pumps are turbine-driven centrifugals, generally of high speed and of few stages. There are a number of installations of motor-driven plunger pumps for feed service. These have relatively good efficiencies for small capacities and high pressures, but they are not favored on account of their limited output and high maintenance.

Blowers are motor driven.

Circulating, condensate, sanitary, and fresh-water pumps generally are motor-driven centrifugals. Ballast and bilge pumps are also often motor-driven centrifugals, provided with self-priming features.

Oil pumps, fuel and lubricating, are usually of the rotary displacement type (gear, plunger, or screw). In a few cases stand-by lubricating oil pumps and fuel oil transfer pumps are direct-acting steam.

For cargo pumps on tankers the rotary plunger type is now general. It is motor driven when the pump room is adjacent to the engine room, otherwise turbine driven. There are some installations of centrifugal pumps for the main cargo units with rotary plunger or direct-acting steam pumps for stripping.

Steering gears are generally electro-hydraulic, though occasionally owners want steam for simplicity of maintenance.

Windlasses, winches, and capstans are electric on passenger vessels; steam on tankers.

Air conditioning is now quite usual for the public spaces of new passenger vessels, especially those plying Southern waters.

Refrigerating plants are motor driven. Freon, as refrigerant, is coming into vogue. This has the safety of CO_2 and the simplicity and lightness of ammonia plants.

The installation of bilge and ballast oil separators to prevent pollution of harbor waters is practically universal.

FEED SYSTEMS.

The passing of the era of moderate steam pressures heralded the importance of pure feed water for the boilers, and steps were taken in that direction. More recently, due probably to the advent of economizers, the demand for complete de-aeration has become insistent.

As to what constitutes a satisfactory de-aerating feed system has been, and still is, a matter of much controversy.

Several systems are now in use, and each has its proponents. They are believed to be of interest, but because the description is long and of a rather specialized nature, its inclusion under the title of this paper did not appear to be justified. It is therefore dealt with separately in an appendix. (Not included in this abstract.)

CONCLUSION.

In common with other lines of endeavor in the United States, marine engineering is influenced by the desire for labor-saving devices, and what may be considered by some as over emphasis on the last degree of efficiency. Both of these tend toward mechanical complication.

On the other hand, the propelling machinery in a ship is there to enable the vessel unfailingly to meet its operating schedule. This requires a high degree of reliability most easily assured by mechanical simplicity.

Between the highest efficiency (complication) and reliability (simplicity) there is much room for difference of opinion and plenty of scope for the enthusiast and the specialist, both of whom influence the trend. The best design will be the one that achieves the desired result with the greatest economy of means.

THE MECHANIZATION OF THE NAVY.

The following article reproduced in its entirety, was written by Admiral Sir Reginald H. S. Bacon, K.C.B., K.C.V.O., D.S.O.., and appeared in the May, 1938, issue of the Journal Royal United Service Institution of London, England. Improvements made in naval machinery since the battle of Trafalgar and their strategical and tactical value are graphically portrayed. A special exhibition depicting "The Mechanization of the Navy," has been in progress at the R. U. S. Museum during the summer months.

It is indeed difficult to condense into the scope of a single article the improvements in the mechanisms of the navy and their effects on strategy, tactics, and the personnel from the sail to the steam turbine, from the *Victory* to our latest battleship, from salt pork and lime juice to refrigerating machinery, from a quart of water a day per man to an unlimited supply of this necessity; and, further, to remark on how these changes have affected armament firms. The advent of steam, iron, and steel, and the growth in perfection of machinery are so intertwined that to treat them separately is impossible, yet to deal with them *en bloc* would result in confusion. I have therefore divided the years from 1815 to 1930 into three periods; the first ending at the year 1889, when the Naval Defense Act was voted and steel came into general use for ship construction; the second from that year to 1900, when long range shooting became a practical proposition; and the third period embracing subsequent years.

THE ADVENT OF STEAM.

On the day that the battle of Trafalgar was fought a boat propelled by a steam engine was ploughing the waters of the Clyde. Little did anyone in the Navy foresee the vast changes that would result in the Service from that microbic venture. The material of the navy at that time, apart from some improvements in the sea-going and sailing qualities of the ships and their rigging, was in much the same condition as it had been two hundred years before in the reign of Queen Elizabeth.. The sole machines carried on board our men-of-war were the capstan and bilge pump. The guns had undergone but slight improvement, the carronade with an embryo recoil-mounting had been introduced, percussion locks had taken the place of the slow-match, but that was all. Steam was, indeed, therefore an innovation.

For the next forty years the growth of steam as a means of progression was slow, unavoidably slow; since, not only was it necessary to design and construct engines of sufficient power to propel large ships, but the sole means then known of utilizing that power was by rotating paddle wheels. These excrescences were an abomination in a sailing ship and an absurdity in a fleet action, since the first broadside would most certainly have put

those vulnerable projections out of action. It was, therefore, not until 1843 when the historic trial of the *Rattler,* fitted with a screw propeller, and the *Alecto,* a sister ship fitted with paddles, brought the advantages of the former home to the Admiralty, that the steam engine became a practical adjunct to the British Navy. Adjunct it was, since for the next thirty years sail power still remained the main means of propulsion for men-of-war, with steam only as an auxiliary for use in case of calm weather or foul winds in entering harbor.

As may well be imagined, so fundamental a change as that from sail to steam was not, in its transition stages, without its humorous side. One memorable incident is worthy of record. A captain, accustomed all his life to a sailing ship, entered a harbor in a light wind under steam and sail. Having furled his sails, he and the crews of the other craft at anchor thought his ship bewitched when she careered about the anchorage with no sail set, until the captain at last realized he had forgotten that the ship was fitted with engines.

Meanwhile vast improvements in machinery were taking place ashore. The smelting of iron went on apace; machines were devised for shaping and boring hard metals; the screw thread no longer had to be laboriously cut by hand, and armor protection for ships became a possibility. At first, attempts were made to bolt iron plates on to the sides of wooden line-of-battle ships, but these experiments proved that such a system was unsound as the extra weight strained the ribs, opened up the seams, and, generally, when the ship labored in a seaway, racked a construction which had not been designed to stand the extra stresses brought about by so great an increase in weight. It became obvious that, if armoring was to become a practical proposition, the hulls of ships would have to be built specially to carry the weight; this necessity compelled the construction of iron hulls for our men-of-war. It is not difficult to understand that such an innovation was stoutly resisted by most seamen. To them it seemed an elementary fact that wood would float but iron would not; and, whereas, a leak, specially if developed during an action, might cause quite a considerable amount of water to enter a wooden ship without incurring disaster, with an iron ship this would not be the case, and a moderate amount of water might cause the ship to founder. Science won the battle; and, following up the experience gained with iron ships built for the merchant service, the *Warrior* and *Black Prince* were added to the list of the navy. Calculation and experience soon showed that the use of iron in preference to wood permitted the building of longer, and generally larger ships, since iron structures proved to be stronger than those of the same weight if made of wood.

The engines first mounted in our ships were indeed heavy and clumsy. Horizontal engines and jet condensers were installed as late as the *Agincourt* class. A low steam pressure only was used in the boilers, so that the engines worked as much on a vacuum as on steam pressure. It was hardly an exaggeration to say that, in those days, a hole on the top of a boiler could be stopped by covering it with a sack kept in place by a brick! The jet condenser, whereby the salt water mixed directly with the feed, necessitated eternal chipping and cleaning of the boilers. It is little wonder that the economical speed of these battleships was about four knots; and it was at this speed that the Channel Squadron usually cruised between Gibraltar and England.

Improvements in engine machinery followed quickly in the next twenty years, 1850 to 1870. The horizontal trunk engine and jet condenser gave way to vertical engines and surface condensers, and a still further step forward was made when compound engines were devised and fitted on board

our ships. To show the revolution caused by this type of engine, it is only necessary to recall the fact that, in 1884 or thereabouts, from fifteen to thirty merchant vessels called daily at Malta for coal; within a very few years this number had fallen to two or three. The economy effected by the compound engine allowed the Black Sea grain steamers to make the round trip from England to Odessa and back, and our Eastern trade to pass from Suez to England, without coaling en route. This revolution had its echo in the navy, for it was no longer necessary to fit frigates and corvettes with sails; with compound engines they were able to steam with certainty from one coaling station to another, whereas hitherto they had been unable to do without the assistance of their sails.

IRON AND STEEL.

The year 1889 may be taken as a red letter year in the annals of the British Navy, for it was then that the Naval Defence Act took shape. By then construction of hulls and engines had advanced so greatly that, instead of steam being looked on as an auxiliary to sail, sail was considered to be unnecessary even as an adjunct to steam. Iron had completely ousted wood for the hulls of our ships. Iron armor was in general use for the protection of the gun positions and waterline. But, in turn, iron had to make way for steel; for it was at this time that steel came to be used universally for hulls, and Krupps steel armor was invented; both of these led to a considerable saving of weight in ship construction.

Let it here be remarked that the only reliable criterion in judging one warship by another is by a comparison of tonnage. On a given tonnage certain dispositions of guns, armor and motive power can be made according to the desire of the Board of Admiralty. If, on a given tonnage, additional speed, or gun power, or protection is desired, this can only be obtained by some sacrifice on the part of one of the other two. The comparative strength of a fighting ship therefore depends on her tonnage and not on any one of the above factors considered apart from the other two. In 1889, therefore, the naval constructor found himself in the happy position of having been given a present of several hundred tons in weight by the use of steel for hull construction and, also, by the adaptation of chilled steel to armor manufacture; so that, for a given tonnage, greater speed, protection, and armament could all be obtained to a degree that had hitherto been impossible.

During the previous thirty years the disposition of the armament in ships had likewise been undergoing a radical alteration. The old broadside disposition of medium-sized guns had gradually given way to the use of turrets. H. M. S. *Captain*—a ship deficient in stability and lost in the Bay of Biscay by capsizing under sail in a heavy squall—and the *Monarch* championed turret construction. These were quickly followed by the *Dreadnought* (*I*), which ship may be looked on as the progenitor of modern design. The *Admiral* class, commissioned in 1889, was an improvement on that of the *Dreadnought*, for those ships were given a central battery of 6-inch guns in addition to two barbettes of two 12-inch guns each. They had, however, two grave defects: the forecastle was so low that they were unable to steam at speed in even a moderate sea, and their ends were unarmored, so that even comparatively small damage in an action would inevitably have caused them to capsize. In the *Royal Sovereign class*—the best of the Naval Defense Act battleships, both these defects were remedied, largely owing to the saving of weight due to the adoption of steel. This class of battleship remained for the next ten years fine models to guide capital ship construction.

Before the end of the century, naval constructors received a further gift owing to the advances made in boiler design, and to the adoption of water

tube boilers. These boilers reversed the principles on which the tank boilers had been designed by carrying the water where formerly the hot gasses passed and the hot gasses where the water previously had circulated. Two great advantages accrued: firstly, the saving of weight, since the volume of water carried in each boiler was considerably less for a given heating surface; and, secondly, the ability to raise steam in a quarter of the time that had been required in the case of the older boilers; for, in the latter pattern, heat was distributed far more rapidly to all parts of the structure; and, therefore, less stresses were produced by the rapid production of heat in the furnaces. Unfortunately the original Belleville water-tube boilers supplied to the navy were badly manufactured. This design of boiler necessitated a number of inspection openings; the covers of these were not bedded properly, consequently a considerable leakage of waetr constantly took place when under steam. This resulted in an undue expenditure of coal. These defects were soon remedied, but they caused a totally unreasonable vendetta to be waged against water-tube boilers in the House of Commons by the partisans of the old type. Considerable political pressure was brought to bear on the then First Lord, with the result that the supply of water-tube boilers was held up, a large sum of money was wasted, and the navy was saddled with eighteen ships of reduced efficiency. But, as is ever the case with mechanism, if not with human beings, truth in the end prevailed and the water-tube boiler was adopted, but not until three years after it should have been fitted in all our new ships of war.

NEW GUNS AND POWER MOUNTINGS.

Up to the end of the nineteenth century the guns of the navy were practically of the same pattern as those made of cast metal and used at the battle of Trafalgar. Such guns were, from the very method of their construction, unable to stand more than a very moderate chamber pressure; their muzzle velocity and range were therefore correspondingly limited. A more scientific knowledge of metallurgy led to the disuse of castings, and a more complicated, but infinitely more efficient method of construction came into being. The improved guns were built up of coils shrunk over a central tube and also on to each other; the compression thus obtained gave a greatly increased support to the chamber. Soon wire strip took the place of the majority of the coils, with the advantage that this strip could be tested throughout its whole length, and, further, it could be wound on at any desired tension. It was therefore possible by this means still further to reinforce the barrel and chamber.

Another radical improvement in ballistics was obtained by rifling the bore of the guns. In muzzle-loading guns this took the form of cutting grooves spirally in the bore in which traveled studs which protruded slightly from the projectiles. By this means, on firing, a rotary movement was imparted to a cylindrical instead of a spherical missile, and much heavier projectiles could be used and far greater steadiness in flight obtained. This method was still further improved after breech-loading guns were adopted, for driving bands of a diameter equal to the bottom of the grooves were fixed to the projectile, these cut into the rifling and formed a gas check as well as a driving band.

The next great improvement came when breech-loading instead of muzzle-loading was adopted for all guns. So long as guns were loaded from the muzzle they had, in the case of broadside mountings, to be kept short to allow the recoil to bring the muzzle inside the port; or, in the case of turrets, to allow rammers to be worked either immediately inside the turrets or at a loading position through the deck in close proximity to the turret.

Loading from the breech permitted guns to be designed of any length consistent with structural strength and rigidity.

With early breech-loading barbette guns, fixed loading positions were adhered to, but so much time was wasted in loading, owing to the necessity of training the turret from the firing position, which usually was approximately on the beam, to the fore and aft loading position, that an heroic solution was found by providing a working chamber which revolved with the turret and allowed the guns to be loaded while pointing in any direction. This reduced the time of loading from three and a half minutes to some thirty seconds.

Ever since its introduction in the *Thunderer,* hydraulic power has been used for loading heavy guns and working the turrets. Only once has hydraulic power been departed from, namely, when electricity was experimented with in one of the later battle cruisers. Theoretically it seemed as if the latter power should be more efficient, but the reverse was proved to be the case, and electricity has never been reverted to for heavy turrets; its use has been restricted to the manipulation of smaller caliber guns.

Projectiles, needless to say, improved *pari passu* with gun design. The installation of armor necessitated the use of a projectile strong enough to pierce the iron. Krupp armor demanded a yet stronger construction, so projectiles with hardened points covered by soft iron caps (which at the moment of impact gave circumferential support to the rather brittle point) came into use. But the eternal war between armor and projectile continued, and probably will continue, for some years to come. Two classes of shell were evolved: one, powder-filled, called the "common" for use against unarmored positions of a ship; the other, "armor piercing," for use primarily against armor. Both could be filled with a high explosive; but, in the case of the armor piercing, the explosive had to be one which would not be detonated by the "set up" shock experienced when the velocity of the projectile was checked on striking the armor. The technical chemists solved this problem.

Propellants also improved with advances in the chemistry of explosives. The black powder of the 'seventies and 'eighties, with its rather haphazard time of ignition, was supplanted by prism powder with a central hole up each prism which allowed of a more uniform generation of gas. This, in turn, was superseded by cordite of a stick-like structure which led to a still greater uniformity of burning, moreover the rate of burning could be varied by alterations in the diameter of the sticks so as to suit the size of gun and to give any desired chamber pressure. Incidentally this form of propellant was destined to cause much trouble ten years later, owing to its tendency to disintegrate and ignite prematurely under the combined effects of age and heat.

THE TORPEDO AND THE SEARCHLIGHT.

Three other important additions to the naval armor eventually vastly affected naval strategy and tactics. First amongst these must be counted the invention of the Whitehead torpedo. Early in the 'seventies, Mr. Whitehead perfected a mechanism for automatically keeping a body when running submerged at a constant desired depth. The resulting torpedo started life with a wrought iron 14-inch cigar-shaped casing and a wrought iron air chamber, and a charge of black powder. By early in the twentieth century, it had attained a speed of twenty-six knots for a range of 10,000 yards, and a heavy charge of high explosive. The early torpedoes ran somewhat erratically, largely owing to their having only a small metacentric height which allowed them to heel and roll under disturbing influences; the horizontal rudders then developed a steering component in the vertical plane.

In due course this was corrected by a gyroscopic attachment which kept the torpedo running in the direction in which it was fired. Compressed air was the motive power of the torpedo up to the end of the century. In order to obtain the full value of energy stored by the compression it was necessary, as the air expanded, to supply more heat than the surrounding sea water could satisfy; this led to artificial heat being provided and a considerable increase in range was effected. Finally, the application of the principles of the explosion engine was responsible for a spectacular increase in the range of this submerged terror.

The second improvement was the development of electrical energy on board men-of-war. Up to 1880 the only electrical appliances on board our battleships were rather inefficient searchlights actuated by an alternating current and a Leclanché battery for firing the guns of a broadside simultaneously. Direct current electricity soon came into use for the searchlights, and brought about far greater efficiency owing to the formation of an intensely hot, and therefore highly luminous, crater in the positive carbon. The light from this concentrated focus was then projected in a parallel beam. Incandescent lighting for ships was first installed for trial in an Indian troopship; and this being favorably reported on, the *Colossus* was so fitted; after which the practice of fitting newly constructed ships with incandescent lighting became general. A good deal of trouble was at first encountered with the dynamo engines, especially in ships with low-pressure boilers, since at the necessary speed of revolution breakdowns constantly occurred in the heavy machinery necessitated by the low steam pressure. Faulty insulation also caused mishaps, and such telegraphs as were supplied for trial proved unreliable. Even in ships with moderate steam pressure breakdowns of the dynamo engines not infrequently occurred. Turbines were tried, but those installed had been put on the market before their mechanical construction had been fully tried out, and cases occurred of their bursting with effects not unlike those of a shrapnel shell. In fact, electricity had a hard uphill struggle before its reputation for reliability was fully established.

The torpedo boat was the third great innovation during the last fifteen years of the nineteenth century. These vessels were originally designed to carry torpedoes to within firing range of an enemy's ship when at anchor in a harbor. Gradually growing in size, they became capable of keeping the sea and working with the fleet. Then, in 1892, a much larger class—the destroyer—was ordered to be built. These latter, when first designed, were intended to counter the torpedo boat concentration in the northern French ports, but they soon took on far more important functions.

STRATEGICAL AND TACTICAL DEVELOPMENTS.

So much for a brief account of the development of the material of the navy up to 1900. It is as well to pause here and consider how strategy and tactics were affected by these developments. First of all we must appreciate that none of the improvements in guns, projectiles, or propellants was devised with the intention of increasing the range of the gun; all were devised to increase the penetrating power of the projectile. Before the beginning of the twentieth century it was not considered possible to increase the fighting range beyond 3000 yards. Of course, the principles of strategy are immutable, but strategy in application must vary with progress of material. The main effect of steam propulsion on strategy, and especially of ships fitted with compound engines, was the development of definite trade routes between various ports. This both complicated and also simplified protection: it complicated because raiders could inflict greater damage, since

the merchant ships could be more easily located; and it simplified by gathering in the ships, more or less, under the wing of the protecting vessels. The net result was that we were forced to build a large number of cruisers to protect our trade routes, and we were also driven to install coaling stations at convenient places to refuel our merchant fleet and men-of-war. These coaling stations required both local and mobile defense, which in turn forced us to increase our fleets on the distant stations. The advent of torpedo craft necessitated very large alterations to our naval bases. The proximity of our South Coast to the French northern naval harbors caused us to build additional breakwaters at Portland and to construct a harbor at Dover. Malta and Gibraltar were also provided with protective moles against the torpedo craft based at Toulon and the African Coast.

It might be imagined that the advent of steam would have made a considerable alteration in the battle tactics of a fleet. This was not so. The fighting formation of the sailing fleet was single line ahead, and this remained the proper fighting formation for battle fleets during the whole of the nineteenth century. It is true that certain heresies were entertained late in that era, but the reason for the line ahead formation was as cogent in 1900 as in 1805; namely, that that formation allowed the maximum of uninterrupted fire to be delivered by a fleet of battleships. Nelson's formation at Trafalgar was, it is true, a departure from a strict line ahead formation, but the variation was dictated rather by the contempt he held for the partly trained crews of the allied fleet than by normally sound tactics. I remember the Admiral commanding the Channel Fleet in 1888 asking the Captains of the various ships for their opinion as to the best formation in which to fight an action. One officer replied that he considered the best to be "columns of sub-divisions in line ahead disposed quarterly." When asked for his reasons, he replied that this formation seemed to him "to be as good as any other." That an Admiral should have asked such a question, and that a Captain should have considered that "any formation would do," is evidence of the chaotic condition of tactical ideas prevalent at that time. But, in mitigation, it must be remembered that the effective battle range up to 1900 was considered to be only from 2000 to 3000 yards. The torpedo range of 800 yards was too short to affect the commencement of a battle. In fact, the use of the torpedo at this time was considered to be chiefly to prevent a ship being boarded, or to disable a ship which missed an attempt to ram. It was generally expected that the line of battle would, as in the old days, break up into a series of ship duels, and that boarding was a probability. In fact, boarding stations formed part of the training of the crews, and cutlasses, boarding pikes and tomahawks were supplied for use during such an operation up to the year 1904.

Previous to 1900 wireless telegraphy had not advanced beyond the stage of being an interesting experiment. It is needless to expatiate on the help this invention has, since then, afforded both to strategy and tactics.

THE "DREADNOUGHT" ERA.

Such were the conditions in the Navy at the opening of the twentieth century, the first ten years of which were destined completely to revolutionize the Service. The most important factor in this was a development of long range fighting. Our heavy guns had for some years been able to fire with accuracy up to 10,000 yards; but hitherto, it had generally been accepted that the difficulties of observation of fire rendered hitting hopeless at such ranges. We had advanced little beyond the times when the range of the target was obtained by measuring the angle subtended by the distance of such an object from the horizon as viewed from aloft and measured with a sextant.

Range finders revolutionized this antiquated method, and salvo firing promised well to solve the difficulty of ranging by spotting the fall of the shell near the target, always provided that sufficient projectiles were available in each salvo, and that the time between the salvos was not unduly delayed.

Several essential points emerged from these considerations. First, it was necessary for each ship to have at least eight heavy guns, preferably ten, so that four salvos of not less than four guns each could be fired each minute; and, secondly, that all the other guns which were mounted in the ship were only for use in repelling an attack by small craft. It was found to be impossible efficiently to mix the caliber of guns in the primary armament as hitherto had been the fashion, since, at long ranges, the differences in "time of flight" and "fall of shot" of two or more patterns of projectiles led to confusion. It was undoubtedly better to concentrate all the weight available for the primary armament in one type of gun and mounting. Hence the *Dreadnought (II)* design with a primary armament of five turrets of two 12-inch guns each, and secondary guns as an anti-torpedo armament.

At the same time as the *Dreadnought (II)* was built, a new class of vessels, known as battle cruisers, was designed. Thoughtful naval officers contended that it was useless to employ vessels for scouting purposes which were unable to press home a reconnaissance. The cruisers hitherto built were able only to report the presence of a fleet, but were powerless to determine its constitution. In order to be able to do this a speed superior to, and an armament commensurate with that of a battleship were required. Moreover, such ships could reinforce the van or rear of a fleet after an action had commenced. It was not anticipated that they would engage a battleship unless that ship were already engaged by a ship of her own caliber. Of course, something had to be sacrificed in order to obtain the requisite superiority in speed; these ships, therefore, were more lightly armored and carried fewer heavy guns; the caliber of these guns, however, was the same as those of the battleships. These ships in reality nullified the use of armored cruisers in a battle fleet. It is rather extraordinary that this fact was not fully appreciated during the Great War. Before and after Jutland, the armored cruisers were of nothing like the value to the Grand Fleet that they would have been on our trade routes; and, during the battle of Jutland, they were in fact, more of a nuisance than a help, being neither strong enough to fight nor sufficiently fast to outsteam the battle fleet and take up their assigned stations during the run South. The loss of the *Defence, Warrior* and *Black Prince* illustrates this point.

DIRECTOR FIRING AND MODERN FIRE CONTROL.

The introduction of long-range firing completely altered the whole technique of fire control, and a further advance was brought about by the reintroduction of director firing in a modern form. By the time Jutland was fought, nearly all our battleships and battle cruisers were equipped with this system, whereby their guns were laid and fired from a single master-sight, instead of each gun having its own layer. In reality, the system differed but little in principle from the director firing practiced in 1875, except that the director was now placed aloft, and electrical transmitters had so far improved in reliability that information could be transmitted to the turrets electrically instead of by voice pipe. But the technique of the system was vastly improved.

THE TURBINE.

In the *Dreadnought (II)* design the turbine was first introduced as a means of propulsion for heavy ships. This radically affected the efficiency of our Navy. No ship of size had previously been so fitted. Prior to 1906 a full speed trial, or even a passage at high speed was a period of anxiety to the engine-room staff; and after such a trip the engines were certain to require a lengthy period of overhaul. In those days an engine-room of a man-of-war when a high-speed trial was in progress was a veritable inferno. The noise of the reciprocating machinery prevented any conversation being heard unless shouted close to the ear. Hoses played water on all doubtful bearings, and the splash of the rotary cranks threw miniature shower baths in all directions. In fact, so wet was the place that the men tending the engines were usually clothed in oilskins. In November, 1905, six of our armored cruisers left New York for Gibraltar steaming at high speed. Only three were able to complete the trip at 18.5 knots, and these were subsequently laid up for several weeks for extensive repairs to their machinery. The short stroke of the piston and connecting rods (owing to the necessity for keeping the engines of men-of-war below the armored deck and practically below the water line) and the high number of revolutions this entailed during each of which many tons of weight had their direction of motion reversed, introduced stresses and wear unknown in merchant-ship machinery. In this latter service a long stroke and slow revolutions of the engines were in use since the machinery could with safety be partially installed above water. On the other hand, in the engine-room of the *Dreadnought (II)* even when the ship was travelling at full speed, it was impossible to tell that the engines were not stationary and the ship in harbor, except by the positions of the needles of the several pressure gauges. The *Dreadnought* actually steamed to Trinidad and back—a total distance of some 14,000 miles—at 17 knots, and on arrival at Portsmouth not one single defect was found to exist in the main driving machinery. It is difficult for anyone who knew the Navy before 1906 not to appreciate the difficulties that would have faced Sir John Jellicoe had he during the Great War commanded ships with pre-*Dreadnought* machinery.

THE SUBMARINE.

The Navy gave birth to another class of vessel in the year 1900, namely, the submarine boat. Submarines and submersibles had been manufactured, indeed, some were in commission in foreign navies, before this date; but it was not until the petrol engine became an efficient means of propelling vessels that the submarine became a practical proposition. The steam engines hitherto employed introduced practical difficulties in the efficient working of the boats, chiefly owing to the length of time taken in submerging, the effect on the crew of the high temperatures of the boilers and engines and the large apertures that were necessary in the hull of the boat. All these militated against the success on service of steam-driven submarines. Petrol is by no means a desirable liquid to work with in a confined space, especially in places where ventilation is restricted and electric sparks a commonplace, but this danger had to be accepted for several years until the heavy oil engine had been satisfactorily developed. Propulsion when below water and periscope vision presented no difficulties, and the advent of the gyro compass made navigation as simple as on board surface craft.

The ships of the *Dreadnought* and post-*Dreadnought* program were fitted with numerous auxiliary appliances, such as hydraulic boat hoists which were ideal for hoisting boats in a seaway. Refrigerating rooms rendered the ships independent of constant provisioning, since fresh meat and vegetables

could be carried for many weeks; and distilling machinery, which had long been fitted to steam ships, made them equally independent of fresh water supplies from the shore. Hence by the year 1914 ships had been evolved which could be relied on to be always ready for service as long as their fuel lasted.

Oil had gradually become an alternative to coal for stoking the boilers. At first it was used in conjunction with the ordinary fuel, being sprayed over the hot coal; then, finally, the boilers were fitted to burn oil only. The main advantage was simplicity and rapidity in fueling the ships generally. The crews of small oil fuel ships, which during the War were frequently in harbor for a few hours only, could enjoy much longer periods of rest than would have been the case if they had had to undertake the arduous duty of coaling ship.

It was during the first ten or twelve years of the twentieth century that startling improvements were effected in the Whitehead torpedo. The increase in diameter from 18 to 21 inches enabled the explosive charge to be increased; and improvements in the engines added largely to its effective range. This additional range was responsible for new tactical problems; for example, when a single line of battleships engages a similar line of the enemy the ratio of ships length to blank spaces is roughly as 2 to 3; hence the chance of a torpedo hitting a ship in such a line is also as 2 is to 3. This fact endowed the torpedo with a certain influence over the tactics of a fleet. It imposes on the Commander-in-Chief the necessity for countering an attack if made by a wave, or several successive waves, of attack by the enemy's fast torpedo-carrying vessels. Superior speed allows an Admiral to choose the range best suited to his armament and the training of his crews, but the threat of the torpedo attack at times imposes on him the necessity for altering that range, however great may be the disadvantage of so doing. On the other hand, the range of modern fleet actions to a great extent rendered useless the torpedo armament carried on board large ships; and such armament, which occupies considerable space on a ship, can with advantage be dispensed with.

The developments in the torpedo, torpedo-carrying craft and blockade mines have altered the attributes of the capital ship. Whereas in the nineteenth century a battleship was both an offensive and also a self-defensive unit, in these days she lacks defensive powers, and other vessels have to supply this deficiency. A battlefleet is therefore not, as in old days, a self-supporting unit, but has for its own defense to be accompanied by a host of smaller vessels.

SPECIALIST PERSONNEL.

The progression from sail to steam, from 1850 to 1914, naturally caused far-reaching changes in the nature of the personnel. A new engineer and stoker class had to be recruited to manage the machinery and effect repairs. Then the whole outlook of the officers and men also underwent a complete change. Instead of muscle and agility being the main desiderata in the men, and education and the three R's at a discount, physical qualities, other than health, have become of less value than technical education. The crews, in fact, have become engineers rather than seamen, that is in the sense that this term was applied to sailors of the old school. With the growth of education, naturally the conditions of life on board ship were bound to change, and more comfort and better living conditions generally became a prime necessity. If it were possible for an A.B. rated in 1938 to find himself on board a man-of-war of 1850, not only would he be utterly use-

less, but he would be thoroughly disgusted at the conditions of life he would there encounter; and, alternatively, if a seaman of the old school were to find himself on board a modern man-of-war, he again would be largely useless and quite aghast at the refined manners and customs of his shipmates.

The effect these changes wrought on the officers of the fleet is no less marked. Nelson's dictum that "no Captain could do wrong who placed his ship alongside one of the enemy" epitomizes the requirements of a naval officer in 1805. The requirements then were physical rather than mental. In these days it is difficult to over-estimate the mental equipment desirable in an officer, especially an Admiral. The belief, sound enough in bygone days, that gallantry only was required to win an action is, in these days, a pernicious doctrine. Now no physical virtue can override the necessity for an Admiral possessing a thorough knowledge of his profession and of the functions of all vessels under his command in war-time. The unobtrusiveness of knowledge must, in modern times, supplant the pageantry of personal gallantry and achievement.

COMMERCIAL ASPECTS.

The effect of progress in armaments on private firms has led to the sinking of a vast quantity of capital in machinery and plant in order to cope with Admiralty requirements. The possession of this plant has, in turn, led to our country receiving valuable orders from abroad for steel, steel products, and for ships and their armaments to an amount which may be fairly estimated as being, before the war, several millions annually. The orders from the Admiralty were of the greatest value to the armament firms in that they provided a more or less constant annual amount of work which went far to reduce overhead charges; they were therefore able to tender favorably in the world markets. Whenever orders for naval armament have been unduly restricted, an immediate repercussion has been felt throughout the country; and unemployment, poverty and suffering have resulted. The old slogan that "armaments are unproductive" and that therefore money spent on them was wasted, is an absurdity. No money that is spent can be looked on as "productive" unless it supplies directly or indirectly necessities for the life and health of the community. All other expenditure, whether for home or foreign consumption, is quite as unproductive as that spent on armaments. When our country possessed a powerful navy we were respected and looked up to by all. So far as the smaller nations were concerned this respect led to confidence and in turn confidence led to the placing of commercial orders since delivery was guaranteed and stability in commerce assured. Another point in favor of spending money on armaments is that such expenditure causes money to circulate among some seventy different trades, and since money that is spent changes hands on the average several times in the course of the year, armament orders are of as great a value to the country as money spent on motor car factories or any other of the hundreds of luxuries which do not affect the life and health of the nation.

The steady progress which has changed the whole nature of our Navy has not been due to the labors and brains of a few men only. Men of all nations have contributed to the scientific and engineering knowledge that has been necessary to effect this transformation. Naturally certain names spring to the mind in this connection; but it would be invidious to particularize, and by so doing assign to them credit which, in reality, should be largely shared by the more obscure workers who helped to bring their labors to a satisfactory conclusion.

CONCLUSION.

Finally, all the above changes in the navy are entirely due to the outcome of scientific research and inventions, and improvements in machinery. Not only have these changes altered the whole of the navy, its strategy and tactics, but they have, by increasing the complexity of our ships and from the more accurate knowledge required in tactical dispositions, altered completely the educational requirements of the officers and men who man the mighty vessels of modern naval warfare. But in congratulating ourselves on this progress and on the efficiency of our fleet, let us fully recognize that improvement is not always an advantage, and that modern machinery has rendered our country far less secure against foreign aggression than it was when defended by our old, poorly educated but gallant seamen and the wooden walls of our old-time sailing ships.

DIVIDENDS FROM RESEARCH.

This address of Dr. A. E. White, President of the American Society for Testing Materials, was delivered at a meeting sponsored by the A. S. T. M. Chicago District Committee at the Chicago Engineers Club on April 22, 1938, and appeared in the May, 1938, issue of the A. S. T. M. Bulletin. Dr. White is Director of the Department of Engineering Research and Professor of Metallurgical Engineering at the University of Michigan.

Doctor Millikan, in his "Science and the New Civilization," tells us that in 1927 the Bishop of Ripon in his sermon on "Science and Modern Living" expressed the thought that we were gaining new scientific knowledge faster than we were developing our abilities to control ourselves, faster than we were exhibiting capacity to be entrusted with these new forces, and hence he suggested that science as a whole take a ten-year holiday. When asked what he meant by a ten-year scientific holiday, he stated that he had in mind a vacation for physics and chemistry and the parts of biology not associated with the improvement of health and the alleviation of suffering.

The question which the bishop raised is proper enough, but the conclusion is faulty. Physics and chemistry cannot take a vacation without turning off the power behind most of the other sciences. The fear of knowledge is as old as the Garden of Eden. Prometheus was chained to a rock and had his liver torn out because he dared bring knowledge from the gods to men. Lavoisier, the father of scientific chemistry, was beheaded in 1794 because his contemporaries held "the Republic has no need of scientists."

Although the guillotine is now out of date as a method of destroying scientists and scientific investigations, all too many business men have applied the ax to their companies' research activities with utter disregard of the consequences.

What a consolation it is to find concerns, and there are many of them, that support research year in and year out, much of it of a fundamental character, with full recognition that their continued growth depends on it. The leaders of these concerns are the ones to whom we can point with pride and the companies in which they are interested are the strong ones in the country.

It is particularly refreshing to find concerns of this type in these days when the administration of industrial activity is much more complicated than it was in the past. The word "complicated" is used advisedly, because, with rates of pay rising, added costs due to the maintenance of Social Security, the lowering of tariffs on many products, the almost vertical increases in

taxes, and the material decrease in demand for products which exists at the moment, it is a much more difficult task successfully to carry forward in industry today that it was in almost any previous period in our history. It is interesting to note, in this general connection, that no less a financial authority than Barron has recently recommended the purchase of stocks making chemical products, with an appreciation that one of the basic reasons for this recommendation is the fact that the industry is founded upon and dependent upon research.

SCIENTIFIC AGE.

We are, without question, living in a scientific age. How true this is may be appreciated by the fact that within the past sixty years such things as dynamos, electric motors, transformers, rectifiers, storage batteries, incandescent lamps, phonographs, telephones, internal combustion engines, aircraft, steam turbines, wireless telegraphy, radio, mechanical refrigeration, and many other developments have become present-day commonplaces. Each one of the items mentioned is a story in itself; a story of scientific achievement and development. One would not recognize, for instance, the present-day electric light bulb from the standpoint of lumens or cost of operation as the successor of the early carbon filament lamp. Nor would one recognize the high-powered automobile of today as the outgrowth of the single-cylindered, side-cranked engine of thirty years ago.

As was pointed out by former President Hoover in one of his addresses, we are in a world of scientific development and achievement. We must look to science and invention as a potent force to assist in leading us out of the depression in which we now find ourselves; for some vitalizing condition is necessary to serve as a stimulus in overcoming the forces of non-production. The discovery of gold in California served such a purpose in 1849, and the railroad development was a vital factor in overcoming the effects of the 1873 panic. The opening up of new lands in the West by the Government has been a stabilizing force ever since this country was established and particularly from the days of the Civil War to the World War.

We do not now have those lands, at least to the extent and the amount which we had in years past, and, therefore, we cannot look to homesteading to be a potent factor in improving the present-day industrial situation. To be sure, we might enter into reclamation work, because there are millions of acres thus available. This reclamation would provide employment, as well as add extensively to the country's millions of tillable acres. It is questionable, however, if such a procedure at this time is economically wise, because the agricultural interests of the United States are still greatly suffering from the evils of over-production, although this difficulty has, in part at least, been met by the work of the Government in limiting production of such agricultural products as cotton, grain, and others.

SCIENCE AND INVENTION—INDUSTRIAL ACTIVITY.

It would appear, therefore, that if the viewpoints of industry and Government can be reconciled, science and invention are going to prove most potent factors in increasing industrial activity. To be sure, there are those who contend that science and invention are responsible in large measure for the depression which has come upon us. The engineer is blamed by many economists for replacing manpower with machinery and thus materially contributing to the unemployment of millions of people in this country. It is true that because of the machinery that has been developed a given individual can turn out much more work than was previously the case. This is amply dem-

onstrated by our automobile factories. The foundry is equipped with continuous conveyors. Sheet metal is pressed into shape for bodies and fenders in one operation. Body finishes are now done in about one-fifth as many hours as it formerly took days. The machine shops are veritable labyrinths of high-speed operation.

When one appreciates that what holds true in the automotive industry holds true, at least in part, in all other industries, it is reasonable to expect that certain groups, without a full analysis of the situation, may charge that the engineer has been a very material contributor to unemployment.

Let us, however, analyze this condition a little further. Let us assume that we have had none of the benefits of science and invention. In that case, we would not now have automobiles; we would not have our present automobile factories employing, even at the present time, a considerable number of men and in normal periods a very large number of operatives; our oil industry would not have developed to the giant which it is today; we would have but a few isolated cement plants; we would have no expenditures for highway construction of any magnitude; we would not require the vast army of workers in every village, town, and city for the maintenance of our garages; our glass factories would be relatively small and insignificant; our rubber industry would be but a puny infant; our woolen mills would need to be only half as large as at present; our requirements for cotton would be much more limited than at present, because one of the major elements in present-day automobile finishes is dissolved cotton; the leather market would feel a materially decreased demand for its products; twenty-five per cent of the requirements of our steel mills would be eliminated; the vast demands of the industry for copper and lead would not exist. We can, therefore, very properly state that, although the automobile industry is one of the industries which tries to operate on as economical a basis as possible, it is an industry which extends its roots and tendrils for raw materials to the very farmer himself, in its requirements for wool, cotton, and leather. Its start was embedded in the internal combustion engine, and its progress has been one of consistent growth as the result of scientific developments and improvements.

Thus, one can state, without any question of a doubt, that, although the automobile industry, with all of the developments that have taken place in it during the past thirty years, has been a most potent force in providing employment in this country, in spite of the fact that it has brought into being large numbers of labor-saving devices.

Let us take another case: that of plastics. A few years ago, the only plastic on the market was Bakelite. Today there are many types which furnish employment to many thousands of people. One of the most interesting of these developments is Plaskon. It was started by a far-seeing business man in Toledo, who wished to develop a suitable product for the platform of the scales made by the company with which he was connected. The problem was taken to Mellon Institute. It was investigated there for a number of years, involving thousands of dollars of expense before a suitable material was produced. The company began producing this material and within the past two or three years it has met with such success that not only have they paid for the cost of the original research, but they have also paid for the cost of equipping a plant engaged in producing it and have returned to the stockholders worth-while dividends.

In another case, the president of one of our large corporations saw the need for an improved single-phase motor. He brought this problem to the University of Michigan. It was with considerable hesitation that the problem was accepted, due to the fact that it was in a field to which large manufacturing organizations were giving consideration. Yet, such outstanding

changes were made in the single-phase motors as then produced that today practically all of the single-phase motors made in this country are manufactured on the basis of the designs and patents worked out by the man who directed this work. When one realizes that the motors in our electric refrigerators, in our fans, and in other such parts are of the single-phase type, one can appreciate the field.

VALUE OF RESEARCH.

The price which many companies have paid for failing to recognize the service of research is a matter of record and history. An outstanding example is that of one of our large talking machine companies. Up to about 1920, its history had been one of almost continual growth. Beginning about that time, the radio industry interfered materially with the activity of the talking machine company. Furthermore, about that time, the American Telephone and Telegraph Co., in its work relating to the further improvement of telephone transmission, discovered how imperfect the then existing records were in the reproduction of all of the high and low tones. With this finding, steps were taken to improve the character and quality of records, with the result that there are now available, or will shortly be, records which give almost perfect reproduction.

Let us take another example. The cotton industry has been hard hit, particularly that part of it making women's stockings and lingerie. It was hard hit in the days of '28 and '29, which were years of unparalleled prosperity. Therefore, the failure of the public to buy cotton goods could not be charged against the world's economic condition. One of the major troubles was that rayon, a synthetic product, was meeting with marked favor with the buying public. These operating cotton mills had failed to be guided by certain fundamental principles. The first question they should have asked was, "What is the most popular type of fabric for these products?" The answer would undoubtedly have been "silk." They should then have asked, "Why is not silk used more extensively?" and the answer would have been, "Because of its cost." They should then have taken steps to find or develop a fabric like silk and yet considerably less expensive. Had they done so, they would have found rayon, because, in principle, it was known since 1846 and was exhibited by Count de Chardonnet at the Paris Exposition in 1889.

However, in this general connection, many of the mills have awakened to the situation that confronted them and are now engaged in the production of fabrics, many of them cotton, which have a definite appeal to the women buyers of the country. Thus, these concerns are benefiting through applications of scientific research to their industry.

The baking industry serves as another illustration. Twenty-five years ago, most of the bread in the United States was baked at home. One of the reasons for this was because the bread obtainable at bakeries was of such a varying quality. Today, as the result of the activities of the American Bakers' Association, most of the bread eaten in the United States is made in bakeries. The improvement in quality has been so great that, with all due respect to our housewives, bread of equal or better quality can be obtained from our bakeries than can be made in most of our homes.

Our paper mills are all passing through a transition, especially those engaged in the production of book paper. This has been very largely brought about by the research work of one of our large ink-producing companies which has succeeded in bringing out a fast-drying ink so that magazines such as "Life," and others which are filled with illustrations, can be printed at a speed unthought of but a few years ago. This has demanded a new type of book paper which has involved research on the part of the paper manu-

facturing concerns. Also, it has required replacement with new and rapid printing machines. Therefore, the research in the field of ink-making has wrought a veritable revolution in the field of book papers and printing presses.

Most concerns pass through periods of prosperity and depression. All, of course, are affected by periods over which they have little control. Many of them, however, bring this condition about as the result of their own individual policies. In this present period, I venture to state that in spite of the necessary adjustment of the world's economic conditions before the depression can end, research will play its part as never before and that those industries which sponsor and support research and, in consequence, develop and produce new products for which there will be a general demand, will be the ones in the forefront in the march from depression to prosperity.

MISCELLANEA OF INTEREST TO NAVAL ENGINEERS.

U. S. TANKERS AS NAVAL AUXILIARIES.—World Petroleum, New York and London, April, 1938.

Coordination of the general maritime policy of the United States with the needs of the Navy and the operating requirements of oil companies was the outstanding development of the past year in the American tanker field. It was signalized by the announcement, in December last, that Standard Oil Company (New Jersey) had agreed to undertake the building of twelve 16½ knot service-speed vessels incorporating features that would make them available for naval use, the government to pay the additional expense involved. The same terms were offered to other oil companies and it is the expectation of the Maritime Commission that contracts for additional tankers will be closed within a short time. Two of the vessels building under the contract with Jersey Standard have been allocated by agreement to Keystone Tankship Company of Philadelphia.

For a number of years officials of the Navy Department have been waiting anxiously for determination of a definite maritime policy by the United States to improve the Navy's position in the matter of auxiliary oilers, which was a cause of growing concern with the increasing obsolescence of its own tanker equipment. During 1937 the Department proposed to convert five of its steam driven tankers to geared Diesel drive, but apparently was unable to obtain the necessary appropriation. Congress, however, did authorize the construction of a new naval tanker of about 12,000 tons deadweight, although no actual appropriation was made last year. It is now probable that the government will take over one of the 16,300 deadweight ton vessels ordered by Jersey Standard, inasmuch as the cost will be less than that of an individual vessel designed to naval standards.

Of consequence in surveying the present status of the U. S. Navy Department's tanker fleet are the general details outlining the obsolescence of the vessels and their efficiency, or lack of efficiency as the case may be, for operation in connection with fleet activities. These statistics are favorably affected by the withdrawal in recent years of the least serviceable vessels, but up to now these have not been replaced. According to the last available list the fleet consists of but 18 oilers aggregating 192,766 deadweight tons, or an average size of 10,709 tons deadweight. Individual sizes range from 3766 tons to 12,600 tons and they are readily divisible into three distinct classes of vessels. The most modern and up-to-date fleet tender is 17 years old, others increasing in age up to 23 years. They vary in speed from 8.5 knots

to 14 knots maximum, with an average of 11.6 knots, and in the entire fleet there are only a half-dozen moderately fast ships—which total 57,600 tons deadweight—attaining service speeds of 14 knots as compared with naval tankers of other nations having service speeds of 15, 16 and 19 knots.

Considering these factors it will be readily seen in what a critical position the U. S. Navy is. With contracts already placed for a dozen fast geared-turbine tankers, the Department can breathe a little more easily, although its requirements are by no means satisfied.

UNITED STATES NAVAL TANKER FLEET.

Oiler	*Deadweight (Tons)*	*Speed (Knots)*	*Age (Years)*
Brazos	9,500	14.0	19
Cuyama	9,700	14.0	21
Kanawha	9,800	14.0	23
Kaweah	10,200	11.0	19
Laramie	10,200	11.0	18
Mattole	10,200	11.0	18
Maumee	9,800	14.0	22
Neches	9,400	14.0	18
Patoka	12,600	10.5	19
Pecos	9,400	14.0	17
Ramapo	12,600	10.5	19
Rapidan	12,600	10.5	19
Robert L. Barnes	3,766	8.5	21
Salinas	12,600	10.5	18
Sapelo	12,600	10.5	18
Sepulga	12,600	10.5	18
Tippecanoe	12,600	10.5	18
Trinity	12,600	10.5	18

The report of the Maritime Commission stated that immediate requirements included the construction of 20 tankers, and that 40 would be necessary during the next five years. Definite negotiations are under way with several other oil companies for slightly smaller vessels—12,000 to 14,000 tons deadweight—some Diesel propelled.

Originally, the Commission solicited 28 companies with regard to construction of these vessels.

Most likely to take immediate action by way of early high-speed tanker construction would appear to be Sun Oil Company, The Texas Corporation, and Socony-Vacuum. The first two have a distinct preference for Diesel propulsion.

The Navy Department will let the oil companies build additional vessels in accordance with their own time requirements. The immediate urgency has been met, and the Department is not setting any definite schedule of vessels per year. As the figure of 40 vessels set by the Commission was a minimum, the number to be built will be limited only by the appropriation available.

VIENNA STORES 1700-LB. STEAM.—Abstract by Power, New York, N. Y., May, 1938, from the Steam Engineer, London, February, 1938.

Simmering Power Station, Vienna, Austria, has installed the world's first 1700-pound pressure accumulator, constructed by the Wiener Lokomotiv Fabriks AG in Vienna, according to their own patents and that of Ruths

International Accumulators, Inc., in association with the Electrical Works of Vienna.

Hydro stations furnish the principal electrical supply of Vienna; the two steam plants in the city supply only 10 to 20 per cent of the demand. Serving as standby stations, these must take loads up to 40,000 Kw. in a few seconds. Simmering, in particular, must keep turbines on the line at all times to pick up unexpected loads. This explains the high-pressure-steam accumulator and a special quick-starting boiler.

The accumulator has a capacity of 27,500 pounds of steam over a pressure range from 1700 to 500 pounds. Final temperature of stored steam varies from 570 F. at beginning of discharge to 475 F. at the end. In the first four minutes, the accumulator can deliver 4400 pounds of steam per minute. It consists of eight storage drums arranged in four pairs, one pair above another. Internal diameter is 39.3 inches, wall thickness 2.83 inches, length 30 feet.

DRUMS.

Vitkovic steel works (Czechoslovakia) forged the drums from single ingots. Inner and outer surfaces were machined and ends closed with flat disks about 1 foot thick, screwed in and seal welded. To avoid openings in drum walls, all piping connections and manholes are in the end plates.

The two highest drums (1 and 2), called the "superheater accumulator," are inter-connected on water and steam sides. The remaining drums (3-4, 5-6, 7-8) constitute the "main accumulator." During both charging and discharging, saturated steam is delivered from the steam side of the superheater accumulator to the lowest pair of drums (7-8). Thence it flows first through 5-6 and then to 3-4. The main accumulator delivers saturated steam

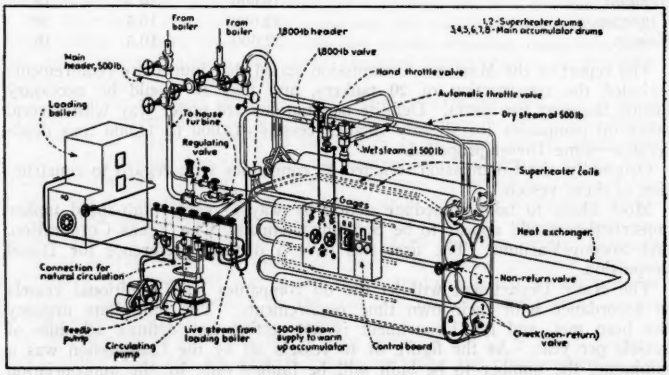

FIGURE 1.—PIPING CONNECTION OF SINGLE-TUBE CHARGING BOILER (LEFT), FEED PUMPS, CIRCULATING PUMPS, INSTRUMENT PANEL AND 8 STEAM-STORAGE DRUMS.

to the throttle-valves, which reduces pressure to 500 pounds. The high-pressure steam becomes wet during this throttling and is then dried in the superheater coils in drums 1-2.

When discharge starts, superheat ranges from 70 F. to 120 F. according to the quantity of steam flowing through the superheater coils. Range is from 9 F. to 18 F. at the end of discharge.

Discharge piping and valves are so constructed that the entire capacity of the accumulator can be delivered in 8½ minutes, and in such a manner that a constant rate of 4400 pounds per minute is possible for the first four minutes. There are two throttle valves, the first oil controlled, operating automatically, the second, hand operated.

Drums are lagged with aluminum-foil insulation (8 inches thick), protected by a sheet-iron covering. Heat losses of the fully loaded accumulator are 240,000 Btu. per hour.

Accumulator discharge is controlled from the pressure of the main steam header in the boiler room. When header pressure falls to a predetermined value, oil pressure from the pressure regulator opens the throttle valve from accumulator to main header.

Two ways to charge the accumulator are provided: a special boiler and a heat exchanger. The special boiler is a "one-tube" generator (of Floridsdorf Witkowitz design). This single tube forms (in its various coils) economizer, furnace waterwalls, steaming coils and superheater. A piston pump forces feedwater through it at the constant rate of 6600 pounds per hour. Outlet steam temperature is 935 F. Pressure ranges up to 1850 pounds. Passing into the hot water of the superheater accumulator, this superheated steam generates the saturated steam which passes to drums 7-8 of the main accumulator.

SUPERHEAT REGULATION.

As already noted, feedwater passing through the charging boiler cannot be varied above or below 6600 pounds per hour. Control of fuel oil regulates the superheat. This method of regulation prevents the water in the accumulator reaching too low a temperature, or the water in the drum becoming too hot before reaching the correct water level.

If feedwater supply fails, or if tube temperature rises too high, expansion of the heated tube shuts off oil supply to the burner. Full loading of the empty accumulator with the charging boiler requires about five hours, during which time pressure rises from 500 to 1700 pounds.

Since the charging boiler serves to load the accumulator in a reasonably short time, basic duty of the heat exchanger is to replace heat losses during standby service. The accumulator can be loaded by the heat exchanger, but it requires 24 hours. In the heat exchanger, water of the accumulator is heated with live steam (500 pounds, 750 F.), which supplies the 5000-Kw. house turbine.

The heat exchanger consists of a 50-foot tube (15-inch diameter), bent to a right angle to allow for expansion. Accumulator water flowing through it surrounds four smaller tubes carrying live steam to the house turbine. A valve regulates the fraction of the house-turbine steam flowing through the heat exchanger. All valves and gates were machined from solid steel. For standby service, heat losses of the accumulator are made up by the heat exchanger.

This accumulator went into service last October. To date there has been no trouble and all expectations have been fulfilled.

FLYING AT 30,000 FEET.—Abstract by Mechanical Engineering, New York, N. Y., June, 1938, from Journal of the Aeronautical Sciences.

Regular transport operation of airplanes at 30,000- to 35,000-foot levels will come within the next ten years, according to a paper presented by D. W. Tomlinson at the 1937 annual meeting of the A.A.A.S. and published in the

"Journal of the Aeronautical Sciences," February, 1938. Describing a series of 33 experimental flights at these altitudes made by him in a Northrop Gamma airplane during the past three years, Tomlinson predicts from his observations of conditions at the base of the stratosphere that, after more study, it will play an important part in long-range nonstop flying.

The principal objectives of the experiments were: (1) To choose the best method of supercharging to 20,000 feet and above and equip an engine for rated power operation at 30,000 feet; (2) to determine the actual increase of speed with altitude as a check against theory; (3) to make actual measurements of speed at 30,000 feet further to check computed true air speeds; and (4) to make extended cross-country flights "over weather" to determine force and direction of winds and meteorological conditions at the base of the stratosphere. The first three objectives have been accomplished. Regarding the fourth objective, the author says that perfection of the meteorograph and extensive data from additional flights over many storm conditions must be had before any useful and comprehensive conclusion can be reached about weather and winds on top of storm areas.

Choice of a supercharging method lay between the gear-driven impeller and the exhaust-turbine types. Whereas the gear-driven supercharger reaches maximum efficiency at only one cruising altitude, the turbine supercharger is sufficiently flexible in its operation to enable a pilot flying above the critical cruising altitude to utilize it as desired when cruising at full engine throttle. In this case the engine power diverted to supercharging is limited to that actually required above the energy recaptured from the exhaust gases.

The oxygen equipment in the cabin consisted of a 15-liter bottle of liquid oxygen with a vaporizing coil heated by hot air from the intensifier tube in the exhaust manifold and two lightweight gaseous-oxygen bottles of 39 cubic feet capacity each. The practice was to use gaseous oxygen for flights of less than two hours' duration, and, as an emergency supply, to supplement with liquid oxygen, for longer flights the liquid oxygen was used. By boosting the pressure in the liquid-oxygen bottle to 15 pounds prior to take-off, adequate evaporated oxygen supply would be available in ten minutes. On several occasions when cruising at 35,000 feet it was found necessary to cut in the gaseous oxygen from time to time to insure an adequate supply, inasmuch as at these levels the crew had to breathe pure oxygen. Also during rapid descents from high altitudes, gaseous oxygen was used when, due to increase in atmospheric pressure, the evaporation rate of the liquid oxygen markedly decreased and the output of the vaporizing coils was no longer sufficient to supply the needs of the pilot and observer.

It was found that complete loss of the oxygen supply at 30,000 feet produced great mental and physical inefficiency in from 30 to 60 seconds, and caused complete unconsciousness in 60 to 90 seconds. Prolonged moderate or severe oxygen want for a relatively short period caused mental retardation and confusion for 30 minutes or longer after the oxygen want had been relieved.

The experiments proved the seriousness of the fuel-supply problem in the stratosphere. Not only is the matter of fuel pressure difficult, but also the matter of evaporation is a question of unknown proportions. It is definitely known that fuel pumps must be completely drowned, located in the bottom of the fuel tanks, and driven electrically or hydraulically. Evaporation losses were not observed during the flights and therefore figures are not available. However, as such loss is inescapable with present fuels, it will be necessary, before extensive operating is done at stratospheric levels, to develop a less volatile fuel, or to put the fuel tanks and the cabin under pressure, even though pressure in fuel tanks is definitely undesirable.

Spark-plug trouble, evidenced by engine roughness, was observed above 25,000 feet. During a series of test flights made in collaboration with the U. S. Army at Wright Field, plugs were removed, tested, and new ones installed prior to flights. It was conclusively determined that plugs were breaking down between 25,000 and 30,000 feet under full-power operation. Better spark plugs than any now available will be required to insure satisfactory operation and life at altitudes above 25,000 feet. A magneto was found to be dead after a climb to 35,500 feet. This failure was caused by the high-tension circuit arcing across from the high-tension outlet to the ground. No difficulty of any kind was encountered from the shielded-ignition harness.

To answer the question which has been raised frequently regarding the reliability of air-speed meter readings at high altitudes, the air-speed meter was carefully calibrated and several flights made at 30,000 feet around a triangular course. The turning points were the cones of silence above U. S. Department of Commerce radio-range stations located at Kansas City, Kirksville, and Columbia, Mo., the lengths of the legs being 128, 78½, and 120½ miles, respectively. From the results of several flights, it was found that the level speed curve of true air speeds at 500 H.P. shows speeds of 165 M.P.H. at sea level and 225 M.P.H. at 30,000 feet. This is an increase of 36.4 per cent, which compares with the theoretical maximum of 38 per cent.

During the flights, the moment the plane touched high cirrus clouds, heavy static was heard in the radio. On a flight to Dayton, Ohio, from Kansas City, the plane, in descending to land, entered a cloud at 30,000 feet and reached its bottom at 8000 feet; 22,000 feet of absolutely continuous cloud. This particular cloud was also different in that it appeared to be a moderate mist instead of having the fog-like aspect of the normal cloud. Also the instant the plane touched the cloud, all radio reception was ended because of heavy static. On a flight to New York, the author's opinion, shared by many others, that storm clouds (thunderheads excepted) did not extend above 30,000 feet was completely altered when he got lost in a storm, the top of which was estimated at 40,000 feet and the area covered by it extended from the Mississippi River to beyond the Atlantic seabaord. Strangely enough, throughout the flight, the air above 30,000 feet was as "smooth as glass." Today such clouds should not offer any difficulty to high-altitude flying, provided planes are equipued with shielded antistatic radio antennas.

As a conclusion to his paper, Tomlinson proposes that the meager knowledge of conditions at the base of the atmosphere be expanded by the Government with the establishment of a special department of the U. S. Weather Bureau. About fifty U. S. Army planes equipped with turbine superchargers, soon to be obsolete from the military standpoint, but still suitable and satisfactory for high-altitude flights, could be made available for the use of this proposed department. In conjunction with this service, a large number of meteorograph stations should be established to augment the data obtained from the airplane flights. Further, it is proposed that Congress grant an appropriation for the development of an experimental high-altitude, high-speed transcontinental air-mail service with planes cruising at 30,000 feet and making not more than one stop. This scheduled operation would provide a proving ground for all the mechanical devices essential for high-altitude flying, including pressure cabins, and pave the way for the passenger transports.

TESTING MATERIALS FOR HIGH TEMPERATUE TURBINES.—Pacific Marine Review, San Francisco, Calif., June, 1938.

The finishing touches have just been added to the third of a battery of unique electric furnaces by means of which engineers at the Westinghouse

Research Laboratories will study the "creep" of steel and metal alloys. The three new testing machines comprise the most elaborate creep testing apparatus in the world.

Before a piece of metal can be safely used in a modern high speed machine, such as a steam turbine, engineers must know exactly how much it will stretch or "creep" under working conditions. For example, the steam inside a turbine is so hot at 850 degree F. that the steel interior glows a dull red. Under the combined action of high temperature, centrifugal force, and steam impact, the grains in the metal slide; the blades creep. Turbine blades are made of alloys which will resist creep to prevent collision after a few years' use because blades are spaced only a few thousandths of an inch apart to operate efficiently.

METALS FACE INCREASING TEMPERATURES.

In the past ten years temperatures have increased radically in steam turbines. "The higher the temperature of the steam, the more elctricity can be obtained from the burning of a pound of coal," explained P. G. McVetty, designer of the new testing apparatus. "But as the temperature of the steam increases the strength of the metal in the turbine decreases," he added.

However, as a result of creep tests, metallurgists have been able to develop alloys which today resist creep at 950 degrees F. as well as the older types of metal did at 850 degrees a few years ago. "The only fundamentally sound solution to the problem presented by higher temperatures," McVetty pointed out, "is to conduct enough tests to make sure that the properties of the weakest material acceptable under the turbine engineers' specifications are known. Turbines can be built to withstand any degree of temperature provided we can find the metal alloys which will creep slowly enough."

It is not at all unusual for the engineers of the Westinghouse turbine division at South Philadelphia to ask Mr. McVetty what stress they can put on a metal so that its creep will not exceed two-tenths of one per cent in 20 years. Another way of putting this is to say that the creep would not be more than one ten-thousandth of an inch of metal a year.

BOLTS "CREEP" TOO.

This specification does not apply solely to blades but to casings and bolts and all other parts that will be affected by the high temperatures. If a bolt should creep enough it might relax and lose its tension.

In the past, each sample of metal was placed in an individual furnace and heated while carrying a heavy weight. Periodically over several weeks the amount of creep was measured by means of mirrors which reflected onto a scale the degree of stretch between two marks on the samples.

Such old style testers were accurate but were not designed for the day when industry required 100 or more simultaneous tests of different materials. Today, metallurgists are developing alloys for high temperature service more readily than they can be tested even with a rasonably extensive installation of the existing equipment.

TEST 180 METAL SPECIMENS SIMULTANEOUSLY.

Mr. McVetty, in effect, has combined 60 creep machines into a single unit. With all three of the new machines in operation, it will be possible to conduct 180 simultaneous tests. Each machine is a heavy alloy steel block housed in a three-walled cylinder taller than a man and supported on a foundation of sand. In order to retain the heat inside the furnace, the outer

shell is made of concentric sheets of polished nickel and aluminum separated by powdered silocel.

PHOTO-ELECTRIC TEMPERATURE CONTROL.

Three electric windings on the metal core of the furnace produce temperatures up to 1000 degrees F. and a photo-electric cell maintains the temperature within 10 degrees or less by automatically operating a resistance which controls the electric current. The cylinder revolves once an hour in order to distribute the heat equally to all parts of the furnace.

When all three units are in operation, the operator will be able to "plug in" by means of a telephone switchboard and determine exactly how the heat is being distributed inside the furnace. One hundred and twenty-five pairs of wires will connect thermocouples in the furnaces with instruments for measuring and recording the temperatures.

Each heating core has 12 spaces for holding twelve 20-inch test samples which may be subdivided into five sections to make 60 tests. Dial gauges connected with comparison rods extending through the top of the furnace measure the relative vertical displacement of the rods by the samples which may be "loaded" by weights and levers to carry 50,000 pounds per square inch of metal under test.

MEASURE 1/100,000 INCH CHANGE.

But for a double check, Mr. McVetty equipped the machine with a circular track and a micrometer microscope called an "extensometer." A laboratory worker welds two platinum spots or targets at the top and bottom of the sample metal, scratches very fine lines on the spots and fastens the sample metal in the furnace. When it is time to take a measurement of the creep, the cylindrical shell is revolved until the sample is opposite two quartz windows which pierce the 10½-inch wall. The microscope is rolled in place on the track, peers through the quartz windows, and measures the distance between the two platinum targets. Its measurements are within one one-hundred-thousandths of an inch from perfection.

The engineers repeat the readings daily for approximately three months, charting the results as a gradual curve. Thus in three months they discover means of estimating how the metal will creep during the next 20 to 30 years.

MOTOR TORPEDO BOATS.—By Francis McMurtrie, Shipbuilding and Shipping Record, London, England, May 5, 1938.

Public interest in motor torpedo boats has been quickened recently by a series of questions on the subject in the House of Commons.

The modern motor torpedo boat has been developed from a design produced early in the great war. Three officers of the Harwich destroyer force suggested that small motor boats might be used with advantage to cross mine-fields and attack enemy bases. In 1915 a firm with a great reputation for the construction of fast torpedo craft, John I. Thornycroft & Co., Ltd., submitted a design for a 40-foot boat with a hull of wood, with a full load displacement of 4¼ tons, driven by a Thornycroft Y 12 motor developing 250 H.P. A number of these boats were turned out, the earlier ones realizing a speed of 33.5 knots, the later ones somewhat more.

There being no margin of weight available for the ordinary method of torpedo discharge, it was arranged that the single torpedo carried should be dropped tail first from a trough in the stern.

Following the success of this design, a larger and faster type, 55 feet in length, with a displacement at full load of nearly 12 tons, was developed by Thornycrofts. All these 55-foot boats had twin engines, which, in the first few, were of 250 H.P. each, but in the later ones were of 375 H.P., producing speeds of 40 knots and over. Two 18-inch torpedoes were carried instead of one, but in some cases an equivalent weight of depth charges was substituted for the second torpedo. For discharging torpedoes from the stern, a long-stroke ram, fitted with an aluminum bell-head and actuated by a charge of 1500 grains of cordite, was installed.

To conceal their real purpose, all these early motor torpedo boats were rated officially as C.M.B.'s, an abbreviation for coastal motor boats.

In 1917, the C.M.B.'s scored their first success against the enemy, when a flotilla of four of the 40-foot type, under Lieutenant (now Captain) W. N. T. Beckett, R. N., surprised an equal number of German destroyers at anchor off the Belgian coast and sank one of them, without loss of a single life. But the crews of the C.M.B.'s were so exhausted on their return to Dunkerque that it was decided to increase the length of future boats to 55 feet, for the sake of sea-keeping qualities. The larger boats proved themselves capable of delivering attacks in bad weather after runs of from 50 to 100 miles. Naturally, they were manned by young officers and men able to endure the hardship and exposure involved.

Toward the end of the war C.M.B.'s were employed successfully as minelayers, a special 70-foot type being evolved for this purpose. In the Zeebrugge and Ostend blocking operations a number of C.M.B.'s did useful work in laying smoke screens and flares, and some of them discharged torpedoes.

In 1919, a flotilla of C.M.B.'s carried out an attack on the Soviet fleet at Kronstadt. Lieutenant (now Captain) A. W. S. Agar, R. N., received the V. C. for sinking the guardship *Oleg,* and several other vessels were torpedoed. Operations in the White Sea and the Caspian also proved C.M.B.'s to be a useful arm.

By the end of the war the Royal Navy possessed well over 100 of these mosquito craft; but during the years of economy that followed,. their numbers gradually declined, as boats wore out without replacement, until the type had vanished from the Navy List.

Simultaneously, the idea of the motor torpedo boat had also been developed in the Royal Italian Navy, which built about 200 such craft during 1915-18. It is true that their speeds were inferior to those of the British C.M.B.'s, and many of them approximated more closely to the motor launch type; but they achieved two notable successes during the war. Captain Ciano, of the Royal Italian Navy, torpedoed the Austrian coast defense ship *Wien* at Cortellazzo in broad daylight; and Commander Rizzo, a reserve officer, sank the battleship *Szent Istvan* off Premuda, at dawn.

Though for some time after the war no notable development took place, Italy did not allow her M.A.S. (an abbreviation of *motoscafi anti-sommergibili,* the official rating of these craft) to become extinct. In recent years they have been built in considerable numbers, and the standard type is now a 69 foot by 14¾ foot by 4½ foot vessel with a speed of 46 knots or more, driven by two 1000 H.P. Isotta-Fraschini motors. Two torpedoes are carried, with side method of discharge, in addition to an anti-aircraft machine gun and five depth charges. A capacity of 1300 Kg. of petrol is reckoned to be equal to a cruising radius of 260 miles. S.V.A.N. and Baglietto have been responsible for the construction of the majority of these craft.

As an experiment, at least one vessel of a larger type, the *Stefano Turr,* of 59 tons, with a length of 105 feet overall, has been built. She mounts four 18-inch torpedo tubes, and is propelled by two Fiat high-speed four-

stroke Diesels. The contractors responsible for her construction are Cantiere Costruzione Mecc. e Aeronautica, of Pisa.

Various other navies became interested in motor torpedo craft after the war. During 1919-36, orders were placed with John I. Thornycroft & Co. for a large number of C.M.B.'s for delivery abroad, most of them being of the 55-foot type. Today they form part of the fleets of China, Finland, Greece, The Netherlands, Siam, Sweden and Yugoslavia. It should be added that China and Finland have also experimented with M.A.S. purchased in Italy. Recently both Finland and The Netherlands have been building motor torpedo boats in their own yards.

France has produced about a dozen home-made *vedettes à moteur,* of from 12 to 20 tons displacement, since 1925. Builders of these are the Ateliers et Chantiers de la Loire, the Société Silbur-Merlan, and the Excelsior Company, while the engines have been furnished by either Lorraine or Wisner. Though the majority of these vessels have now been relegated to harbor service, some of them have attained remarkably high speeds on trials, ranging from 37 to well over 50 knots.

Germany has preferred to build bigger craft, known officially as *schnellboote.* Intended for open sea work, they displace from 50 to 60 tons, but none have so far been reported as faster than 40 knots. The Friedrich Lürssen Yacht und Bootswerft m.b.H., of Vegesack, have built most of them. Some have Daimler-Benz petrol engines, others high-speed Diesels. They are armed with two 21-inch torpedo tubes and carry a couple of spare torpedoes. During the past year the Turkish and Yugoslav Navies have acquired several vessels of this type from the Lürssen concern.

The Russian Navy is credited with the possession of anything from 100 to 150 vessels that are capable of being used as motor torpedo boats. Though the earlier ones are of the motor launch type, a large number are of Italian design, with Isotta-Fraschini engines, stern torpedo discharge arrangements and a considerable turn of speed, probably well over 40 knots.

In view of all this foreign activity, it is hardly surprising that the motor torpedo boat—this time frankly so-called—should have re-appeared in the British Navy Estimates for 1935. Six were ordered in that year from the British Power Boat Company, of Hythe, Southampton; they were of a new type, claiming to possess better sea-keeping qualities than the C.M.B.'s, but in speed decidedly inferior, as their three motors of 500 H.P. each are equal to only 35 knots. At full load their displacement is 18 tons, with dimensions of 60 feet by 13¼ feet, and a draught of 2 feet 10 inches. Two 18-inch torpedoes are arranged for discharge from troughs in the stern, and the armament is completed by eight Lewis guns. In 1937-38 a dozen more boats of the same type were ordered from the British Power Boat Company, the first six having proceeded to the Mediterranean as the First M.T.B. Flotilla. According to the current Navy Estimates, the cost of these 18 vessels averages about £28,000 apiece. They are numbered from 1 to 18.

It is obvious that the weak spot of the above design is the low speed, inferior to that of a destroyer. This must have been made a prime consideration in the other types of M.T.B. that have been ordered during 1937. So far, the only one of these to be delivered has been M.T.B. 102, which is now commissioned as a tender to H.M.S. *Vernon,* the torpedo school at Portsmouth. A full description of her should be of interest.

Built by Vosper Limited, of Portsmouth, at a cost of £22,529, M.T.B. 102 has a speed in light condition of 47.8 knots, and with full equipment has reached 43.7 knots. Her full load displacement is 28 tons, length overall 68 feet, beam 14¾ feet and draught 3 feet 2 inches. She is constructed of mahogany (skin and frames) and Canadian elm (timbers, hog, chine and

gunwale). The deck house and most of the deck fittings, such as mushroom ventilators and scuttle deadlights, are of "Birmabright" sheeting. Two of Kent's clear view windscreens are provided for use in rain and heavy weather. There is a duapod mast with crosstrees to take signal halyards, a wireless aerial stretching from the mast to the ensign staff. There are two alternative steering positions, one for action conditions and heavy weather, the other for entering and leaving harbor and for night work.

In armament this vessel is by far the most formidable of her size in existence. She carries two 21-inch torpedoes, besides two 20-millimeter guns on a twin ring mounting, giving all-round firing.

The three 18-cylinder propelling motors have been manufactured in England under license from the Isotta-Fraschini Works, of Milan. At 1800 revolutions they are equal to 1000 H.P. each. There is a dual starting and stopping system, worked either electrically or by compressed air. The weight of each engine complete, excluding water and accessories, is about 3000 pounds, equivalent to 3 pounds per H.P. developed. There are three propellers, made of a manganese-bronze alloy of special quality. The radius of action at cruising speed—20 knots—is 450 miles.

Though the boat can be run by two officers and five ratings—the same complement as M.T.B. 1 to 18—there is accommodation for a larger number if required. There is also space for stores and provisions for a fortnight's cruise.

Lieutenant-Commander Peter Du Cane, M.I.N.A., R. N. (retired), and Mr. R. E. Lovell, A.M.I.N.A., are jointly responsible for the design of this remarkable little craft.

Other experimental types of M.T.B. are under construction for the Royal Navy, though very little information has been vouchsafed concerning them. One of them, M.T.B. 101, is due to be completed shortly by J. Samuel White & Co., Ltd., of Cowes, with dimensions 67 feet 4 inches by 14½ foot beam. *Jane's Fighting Ships* states that she is to be armed with 21-inch torpedoes and guns in semi-enclosed mountings, and to be propelled by three Isotta- Fraschini motors. Her cost is given in the Navy Estimates as £36,760.

ASSOCIATION NOTES.

Consequent on his detachment from duty in Washington, D. C., Commander Roger W. Paine, U. S. Navy, has resigned as Secretary-Treasurer of the Society, effective 31 August, 1938. Lieutenant Commander Guy Chadwick, U. S. Navy, has been appointed by the Council to fill the unexpired term of office of Commander Paine.

The following have joined the Society since the publication of the May, 1938, JOURNAL:

NAVAL.

Amos, Marion, Lieutenant, U. S. Coast Guard.

Braswell, M. T., Lieutenant, U. S. Coast Guard.

Chandler, C. F., Lieut. Commander, U. S. N. R., 118 West Tulane Road, Columbus, Ohio.

Dean, R. D., Ensign, U. S. Coast Guard.

Estabrook, William S., Jr., Lieutenant, U. S. Navy.

Kaulback, Harold D., Lieutenant, U. S. N. R., 245 Brigham St., Hudson, Mass.

Sweet, W. F., Electrician, U. S. Navy.

CIVIL.

Karr, Richard D., 608 25th St. South, Arlington, Va.

Negri, Rinaldo, Italian Line, Pier 52, N. R., New York, N. Y.

ASSOCIATE.

Foster, J. W., care Ingersoll-Rand Co., Philipsburg, N. J.